The
HOW
AND
WHY
Wonder Book of

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ELECTRONICS

THE HOW AND WHY WONDER BOOK OF

ELECTRONICS

Written by
MARTIN L. KEEN
Illustrated by
GEORGE J. ZAFFO
Editorial Production:
DONALD D. WOLF

Edited under the supervision of
Dr. Paul E. Blackwood, Washington, D. C.

Text and illustrations approved by
Oakes A. White, Brooklyn Children's Museum, Brooklyn, New York

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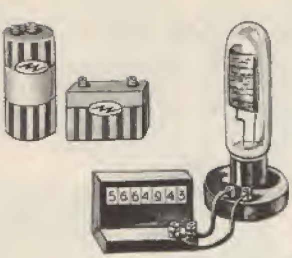

Introduction

About fifty years ago, a famous British scientist observed that the work of physicists was practically completed. There was nothing more to be discovered! Then almost overnight, so it seemed, came the discovery of radioactivity, a new idea about the nature of matter and energy. The atom, which had so nicely been "tucked into bed," was roused for intensive study of suspected new particles and properties. The world of physics was once more alive with discovery.

How foolish it would seem now for a scientist to state that everything about *any* phase of science was completely understood, and nothing further could be learned. As a matter of fact, almost everyone accepts the astounding evidence that the amount of new knowledge is *doubling* at least every ten years. Can you believe that by the time you grow up there will be at least twice as much scientific knowledge as there is presently?

The *How and Why Wonder Book of Electronics* is a sample of the new knowledge that scientists have accumulated in just one small part of the giant field of physics. X-rays, vacuum tubes, radio, TV, radar, transistors, communications satellites, are all examples of modern electronic devices. What improvements will be discovered within the next twenty years? If you are in step with the times, you know that the future holds possibilities that have not even been dreamed of today. For that is the way of man's ingenuity. That is the way of science.

So, as you read this book about electronics, you are preparing yourself not only to understand the "magic" of electrons, but you are laying the groundwork for speculation about new, as-yet-undiscovered, developments of the future.

Paul E. Blackwood

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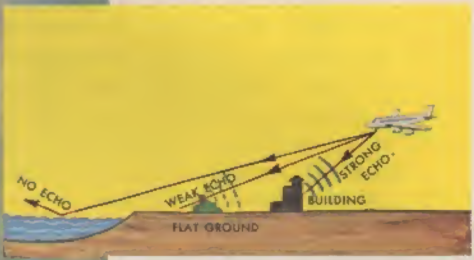
Electronics Everywhere

A giant airliner, carrying more than a hundred passengers, comes in for a landing at an airport shrouded in fog. As the pilot brings the huge aircraft down to the runway, he cannot see more than a few feet in front of the plane. Yet, unseen hands are guiding the great airliner to a safe landing. In the control tower of the airport, technicians watch the plane on radar screens while they radio the pilot careful landing instructions. The pilot, too, is watching a radar screen upon which the airport runway appears as two rows of bright spots. Radar and radio are two very important electronic devices.

A television camera closely follows a football as it leaves the goalkeeper's

Electronics, still a young branch of science and engineering, has grown to giant size. In radio, television, and long-distance telephone apparatus, electronics plays a dominant role in communication. Electronics "thinks" for science, industry, and national defense in computers and computer-controlled devices such as rocket and missile guiding and tracking apparatus. Electronics helps the doctor in diagnoses and treatment.

Almost anywhere you turn electronics is at work.



During his approach to the fog-bound runway, a pilot can see possible landing obstacles which show up on a radar screen on the instrument panel of his aeroplane.

When an airport is hidden by fog, technicians in the control tower watch aeroplanes on radar screens and then radio the pilots careful landing instructions.

foot to soar half-way down the pitch. The camera follows the players as they race after the ball; then the camera points at the cheering crowd. Sitting in your home, you see on the screen of your television set all that takes place in front of the camera at the football stadium. You even hear the thud as the ball is kicked and the cheers of the crowd. The sight and sound of the football game are brought into your home by the electronic equipment that makes television and radio possible.

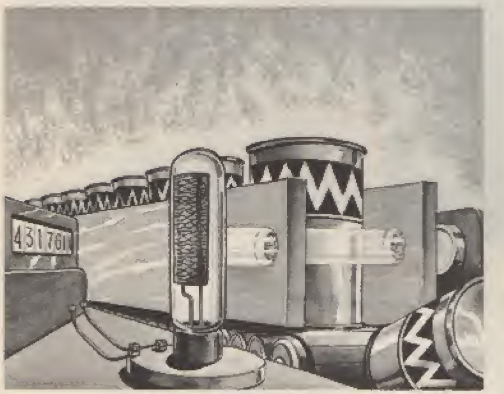
On a long belt in a factory, a line of tin cans moves toward the packing department. Now and then, a steel bar moves across the belt, pushing a dented can off the belt and into a discard chute. The line of cans is inspected by an electronic "eye" — called by engineers a *photoelectric cell* — that notes the dented cans and causes the steel bar to push them off the belt. Another photoelectric cell counts the cans as they enter the packing department.

A doctor wants to know whether his patient, who was in an accident, has broken ribs. The doctor places the patient in front of an X-ray camera that takes pictures of the ribs right through the patient's skin and chest muscles.

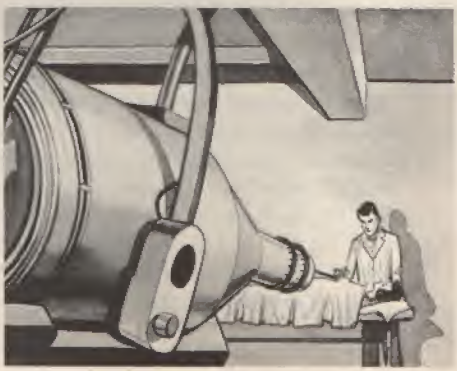
X-ray cameras were among the first electronic instruments to be invented. Besides enabling doctors to see bones and other organs inside the bodies of their patients, X-rays are used in industry. Huge X-ray cameras "see" through as much as five inches of solid metal to detect weaknesses in machine parts. For example, aeroplane wings and wheels of train carriages are X-rayed to learn whether they have tiny cracks that cannot be seen on their surfaces. Examining these machine parts by X-rays prevents accidents that might happen were these parts to break when in use.

Electronic instruments play a large part in scientific research. Atomic physicists work with giant electronic machines such as the cyclotron, which is a huge atom smasher. Scientists, who have large numbers of calculations to perform, turn to electronic computers to save the great amount of time it would take to do the calculations with pencil and paper. Microscopes that use light to illuminate what is being looked at cannot magnify objects more than 2,500 times their natural size. However, a microscope that uses electrons instead of light can magnify objects more than 200,000 times.

All these electronic devices play an important part in our lives. Many, such as radio and television, play a direct part. Others, such as those used in aviation, medicine, and industry, are less familiar to you, but also play a part in your life. From this book we will learn what electronics is and how some electronic devices work.



Electronics in industry: Cans of food move on a conveyor belt from the sealing machinery to the shipping room. An "electric eye" counts the cans, detects faulty ones.



Electronics in medicine: A powerful X-ray unit is used to treat the sick.

Electronics: The Story of the Electron

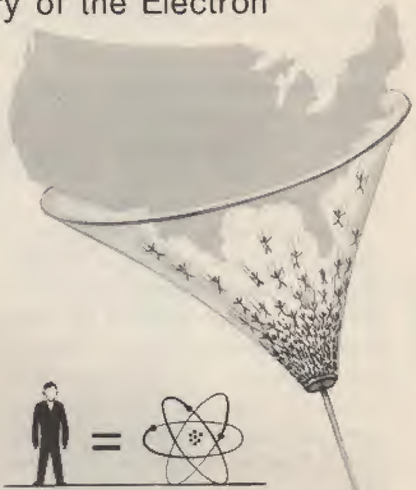
Electronics is the science of controlling the movement of electrons. To understand what this definition means you will first have to learn some things about electricity, because electricity and electronics are very closely bound together. Let us begin by learning what an electron is.

What is an atom?

All materials are made up of very small particles called *atoms.* The paper these words are printed on; the air you breathe; the water you drink; your skin, bones, muscles, and hair — all are made up of atoms.

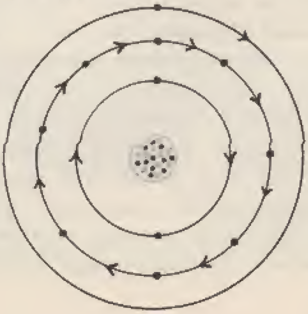
Some substances are made up of only one kind of atom. These substances are called *elements.* Iron is an element. If you were to cut a piece of iron in half, then in half again, and continue to divide it in half, you would finally come to a particle of iron that could not be divided and still be iron. This particle would be an atom of iron.

Actually, it is not possible to cut anything into pieces so small that you arrive at a single atom — or even a piece made up of a million atoms. A single atom is too small to be seen, even with the most powerful microscope. Nor can an atom be detected by any of our other senses. However, despite the smallness of atoms, scientists have learned much about them. One description of an atom that scientists have given us is that of a central part, called the *nucleus,* around which other parts, called *electrons,* revolve. The electrons revolve in orbits around the nucleus



If a human being were no larger than an atom, the entire population of the United States could sit on the head of a pin, and there would still be space for several million more people.

The hydrogen atom (above) consists of one electron revolving around a nucleus of one neutron and one proton. The sodium atom (below) consists of eleven electrons revolving around a nucleus of eleven protons and twelve neutrons.



somewhat like the planets revolve in orbits around the sun. However, only one planet revolves in each orbit. But more than one electron may revolve in the same orbit around the nucleus. The nucleus itself is made up of two kinds of particles, some of which are called *protons* and some *neutrons.*

Each kind of atom has a number of electrons, protons, and neutrons different from all other atoms. The smallest atom has a single electron revolving around a nucleus made up of one proton. As we go to larger and larger atoms, the number of electrons, protons, and neutrons increases to more than a hundred of each in the largest atom.

What is an electron?

An electron is a unit, or single *charge,* of electricity. It is a charge of *negative* electricity. (A negative electric charge is also called a *minus* charge and may be shown in writing by the minus sign —.) A proton is a charge of *positive* electricity. (A positive electric charge is also called a *plus* charge and may be shown in writing by the plus sign +.) A neutron has no electric charge; it is electrically *neutral.*

Ordinarily, each atom has as many electrons as protons; it has equal amounts of positive and negative electricity. When a positive and a negative electric charge are very close together, they act as if they were not electrically charged at all. When this happens, we say that the positive and negative charges *neutralize* each other. Thus, an atom that has as many electrons as protons is electrically neutral; it acts as if it were neither positively nor negatively charged.

Electrons can be easily removed from the outer orbits of atoms of some materials — wool, for example. Electrons are not so easily removed from the atoms of other materials, such as hard rubber. When a material gives up electrons, it has fewer electrons than protons — fewer negative than positive electric charges. As a result, the material becomes positively charged. When a material takes on additional electrons, it has more electrons than protons — more negative than positive electric charges. As a result, the material becomes negatively charged.

How can you collect electrons?

We learned that wool is a material that loses electrons easily. If you rub a hard-rubber or plastic comb vigorously several times on a piece of wool, the wool gives up electrons to the comb. As a result, the comb has a large number of extra electrons. Because the electrons are negative electric charges, the comb is negatively charged. So, simply by rubbing a comb on wool, you have been able to collect electrons on a comb.

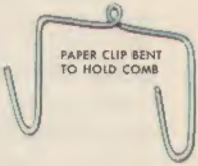
COMB BEFORE RUBBING

WOOL CLOTH BEFORE RUBBING

COMB AFTER RUBBING

WOOL CLOTH AFTER RUBBING

The simple experiment described on this page shows how electric charges react to each other.

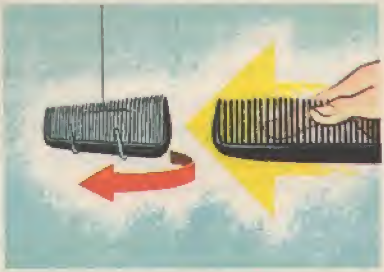


What about the wool? Since the wool gave up electrons to the comb, the wool has more protons than electrons. This means that the wool has more positive than negative electric charges. The wool, then, is charged positively.

How do electric charges react to one another?

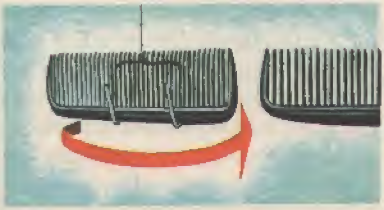
Here is an experiment you can do to learn how electric charges act when near one another. You will need two hard-rubber or plastic combs. Bend a paper clip into the shape shown in the illustration on this page. Suspend the bent clip by a string.

Vigorously rub one end of one of the combs with a piece of silk or nylon cloth. This will remove electrons from the comb and charge it positively. Quickly place the charged comb in the wire holder made from the paper clip.



Like electric charges repel each other.

Unlike electric charges attract each other.



Immediately rub one end of the other comb with the cloth. Now, bring the rubbed end of the second comb near the rubbed end of the suspended comb. The suspended comb will swing *away* from the approaching comb. The approaching comb repels the suspended comb, although the combs do not touch. (To *repel* means to "push away.") Both combs have positive electric charges on their surfaces. This illustrates that like charges repel each other.

Rub one end of a comb with a piece of wool cloth. This will charge the comb negatively. Hang the comb in the wire holder. Quickly rub one end of the second comb with wool. Bring the rubbed end of the second comb near the rubbed end of the suspended comb. The suspended comb will swing *away* from the approaching comb. This happens because the rubbed ends of both combs have negative electric charges on their surfaces, and like charges repel.

Once again, rub one end of one of the combs with silk or nylon cloth and quickly suspend it in the wire holder. Now, rub one end of a second comb with the wool cloth. Bring one end of the second comb near one end of the suspended comb. This time, the suspended comb swings *toward* the approaching comb. The suspended comb has positive electric charges and the other comb has negative charges. This shows that unlike electric charges — positive and negative — attract each other. If you repeat this experiment by suspending the negatively charged comb and approaching it with a positively charged comb, you will find that the two combs again swing toward each other because the unlike electric charges on their surfaces are attracting each other.

To make a certain amount of water flow out of a hose, an equal amount must be pushed into it.

If you think over what happened in the experiment you just did, you will see that it is easy to make a rule, or law, about how electric charges act. We can say, "Like electric charges repel. Unlike electric charges attract." This is the Law of Electric Charges. It means that two positive charges or two negative charges repel each other. It also means that a positive and a negative charge attract each other.

What is electric current?

The amount of electricity you generate by rubbing certain materials together is very small. You could not use this small amount of electricity to heat a toaster, light an electric lamp, or ring a doorbell.

To use electricity, we must have a supply large enough to always have some available when we need it. We must be able to use as much or as little electricity as we need. We must be able to turn the electricity on and off. We like to be sure that when we turn the electricity off there will be more left for the next time we want to use it. We must be able to make the electricity go where we want to use it. We need elec-

No current flows in the circuit (above left), because there is no "electron pump" — no source of power. Current flows in the circuit (above right), because the dry cell acts as electron pump.

tricity that will move evenly — not in sudden bursts. There is a kind of electricity with which we can do all these things. It is *current electricity*.

Current electricity is the kind we use in our homes. We can make it in large quantities. We can make it continually or store it so that it is always available when we need it. We can use as much or as little as we wish. When we turn it on, current electricity flows continuously and evenly through wires to where we want to use it until we turn it off.

Current electricity consists of vast numbers of electrons flowing through wires or other objects. Current electricity is usually called *electric current*.

What are conductors and insulators?

Electric current can flow well through only certain materials called *conductors*. All metals are conductors, but copper, silver, and aluminum are among the best. That is why wires for electric devices are usually made of these metals.

Electric current cannot flow through certain materials called *insulators*. Plastics, rubber, silk, glass, and air are insulators. Electric wires are usually surrounded with sheaths of rubber or silk so that no electric current will flow into your hands when you take hold of the wires. The current flowing into your hands might give you a harmful electric shock.

What is an electron pump?

To keep water flowing through a pipe, we must have a way of continuously pushing water into one end of the pipe as water flows out the other end. We achieve this by using a pump to push water into the pipe. In much the same way, we need a pump to keep electrons flowing through a wire. An electron pump is either an *electric generator* (sometimes called a *dynamo*) or an *electric cell*. Electric cells are usually called *electric batteries*, but this is not entirely correct; a battery is a group of cells that are used together. Because both the generator and the cell push electrons through a wire, we say they generate electric current.

What is an electric circuit?

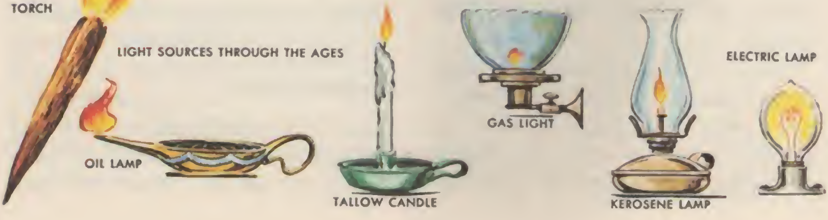
Electric current cannot flow off the end of a wire as water flows out of the end of an open pipe. Air, which is a good insulator, stops the flow of current at the end of the wire. A path for electric current must provide a round trip from an electron pump through wires and other conductors and back to the electron pump. This round-trip path is called an *electric circuit*. Unless conductors form a circuit, electric current will not flow.

Who made the first electronic invention?

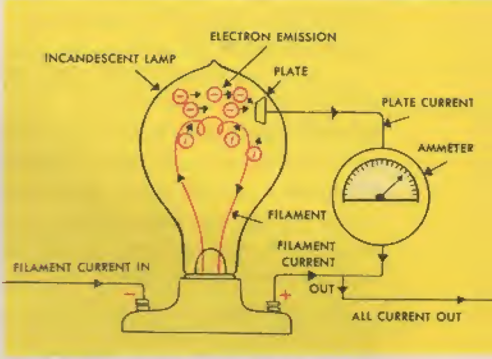
We learned that electric current is the flow of electrons along a conductor. We learned that electrons cannot flow off the end of a conductor as water can flow out of the end of a pipe. However, there *is* a situation in which electrons can be made to leave a wire through which they are flowing. Let us read about a very famous occasion when this took place.

You probably know that Thomas Edison made the first practical incandescent lamp, or electric light bulb, such as those we use to light our homes. In the light bulbs we use today, the light is produced by a small coil of wire, or *filament*, glowing white-hot. In Edison's lamp, the filament was a looped thread of carbon, the same material of which a burnt match or a pencil point consists. When electric current flowed through this carbon loop, it glowed white-hot. But carbon burns when it is heated in air. To prevent the carbon loop from burning up, Edison pumped the air out of the glass bulb, leaving a vacuum. This worked, but soon the inside of the bulb became blackened by tiny particles of carbon from the white-hot carbon loop.

One day, in 1883, while searching for a way to prevent the inside of the bulbs from becoming black, Edison placed a small metal plate inside the bulb. He connected the plate by means of a wire to the electric circuit that heated the filament. He hoped the carbon would collect on the plate instead of on the glass bulb. He also connected to the wire attached to the plate an *ammeter*, an instrument for measuring the flow of current.


LIGHT SOURCES THROUGH THE AGES

A dramatic moment for Thomas Edison was the lighting of his first successful electric lamp in 1879 by current from several electric cells. The filament of the lamp, a loop of carbon thread, was set into a glass bulb from which the air had been removed. When electric current heated the thread to 1900° Celsius, it gave off light. Lack of air in the bulb kept the thread from burning. Filaments of modern light bulbs are tungsten wire.



Schematic illustration of the Edison Effect.

To Edison's surprise, the ammeter registered a small flow of current. This was puzzling because only one end of the wire leading from the metal plate was connected to a source of electricity. The plate was not really part of a circuit. Experimenting further, Edison found that it was only when the plate was connected to the positive pole of the battery that current flowed through the ammeter. When the plate was connected to the negative pole of the battery, no current flowed.

Edison saw no immediate use for his light bulb with a metal plate inside it. Yet, he patented his bulb and plate because he was wise enough to think that someday his bulb might have some use in electricity. He was right about this, but what is really important about Edison's experiment is that his bulb was the first *vacuum tube*. Vacuum tubes are also called *electron tubes*. This is a better name for them because some kinds of vacuum tubes are filled with gas after the air has been pumped out. From Edison's electron tube eventually came all the wonderful devices of modern electronics. Because of this invention, Edison can be considered one of the great-grandfathers of radio.

How does an electron tube work?

Although Edison did not understand the strange results of his experiment, scientists can explain them today.

When we try to "pump" a large amount of electric current through a thin wire, the electrons crowding past the atoms of which the wire is composed give up much energy in the form of heat. The wire glows red- or white-hot. The heat causes many electrons to fly off the wire, like steam boiling off heated water.

The loss of electrons leaves the wire with positive charges. The lost electrons, which are negatively charged, soon are pulled back to the wire by the attraction of the positive charges. However, if there is a much stronger positive charge near the wire, it will pull the electrons away from the wire completely. This is exactly what happened when Edison connected his metal plate to the positive pole of his battery. The positively charged plate pulled electrons away from the white-hot filament. These electrons streamed across the space between the filament and the plate. Then, they flowed through the plate and the wire attached to it and registered on the ammeter as an electric current.

The streaming of electrons from a hot filament in an electron tube is called *electron emission. Emission* means the "giving off" or "throwing off" of something. Whatever causes emission is called an *emitter*. In an electron tube, the filament is an emitter.

Electron emission is the process upon which almost all electronic devices depend.

What are cathodes and anodes?

The part of an electric or electronic device *from* which the current or the electron emission flows is called the *cathode*. The part *to* which the current or emission flows is the *anode*. For example, the filament of an electron tube is the cathode and the plate is the anode. The cathode is negative and the anode is positive. The following table will help you remember these names.

negative	minus	—	"from"	cathode
positive	plus	+	"to"	anode

Radio and Television Broadcasting and Receiving

What are electromagnetic waves?

One of the most important uses of electron tubes is in radio broadcasting and receiving. If we learn how electron tubes work in radio, we shall understand much about how they work in many other kinds of electronic devices. First, we shall learn about *electromagnetic waves,* the scientific name for radio waves.

If you have ever thrown a stone into the water, you have seen the rings that move outward from the spot where the stone strikes the water. The rings, waves of water, are up-and-down movements of the water. They are not made up of water flowing outward from the centre of the rings, even though they look as if they were. You can prove this by throwing a stone into the water near a floating object, say, a small piece of wood. When the water rings reach the piece of wood, it bobs up and down, then the rings pass it by. If the waves were water moving outward from where the stone struck the water, they would carry the piece of wood with them.

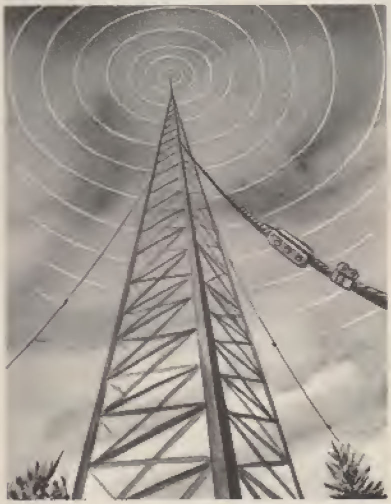
Whenever an electric charge moves suddenly—whether changing direction in a wire or as a spark jumping across a space — the moving charge broadcasts electromagnetic waves. Electromagnetic waves, of the kind broadcast by a moving electrical charge, cannot be detected by any of our senses. We cannot see, hear, smell, taste, or touch them, but we do have ways of detecting them. (Not all kinds of electromagnetic waves go undetected by our senses. Light and heat consist of electromagnetic waves that our senses can detect; we see light and feel heat.)

When electromagnetic waves are broadcast from a moving electric charge, they travel outward from the charge in somewhat the same manner as water waves move outward from the spot where a stone strikes the water. The electromagnetic waves move in a series of spheres. The series of spheres is much like the layers of an onion. The centre of the onion corresponds to the point from which the electromagnetic waves are broadcast. The layers of the onion correspond to the spheres of waves moving outward.

What do wavelength and frequency mean?

Two words that are very important in radio engineering are *wavelength* and *frequency*. We must learn what these words mean. To do so, let us perform an experiment.

Tie a piece of clothesline, or some other kind of rope, to a doorknob. Hold the other end of the rope in your hand and let the rope hang a little slack. Now, move your hand up and down rapidly. You will see the rope shape itself into a series of hills and valleys.



Electromagnetic waves, like water waves, spread out in the form of expanding concentric hemispheres, unless a transmitting antenna is designed to shape the waves into a beam.

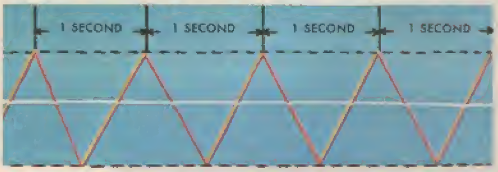
Electromagnetic waves and waves created by a stone striking the surface of water have many things in common.

The waves formed by the rope seem to be moving into the doorknob.

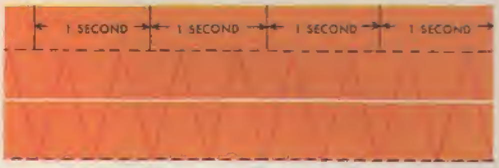
It will look as though the rope were moving into the doorknob, but you know that it is not. The hills and valleys of the rope look much the same as the hills and valleys of rings on the surface of water would look if you were to slice down through the water and look at the slice from one side.

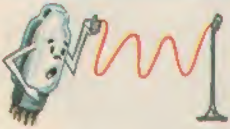
Think of a line drawn from your hand to the doorknob, halfway between the highest and lowest parts of the waves. Distance measured along the line between the beginning of one hill and the beginning of the next hill is one *wavelength*. We could also measure a wavelength between the peaks of two consecutive hills, or between any two similar points on two consecutive waves.

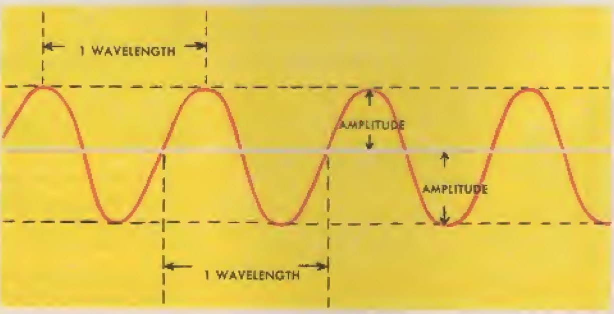
The number of complete wavelengths that pass any point in one second is the *frequency* of the waves. However, frequency is not stated as a certain number of wavelengths, but as so many *cycles* per second, one cycle being one complete wavelength. (Another measure of frequency is the *Hertz* — named in honor of Heinrich Hertz — one Hertz being one cycle per second.) The frequency of radio waves varies from thousands to tens of billions of cycles



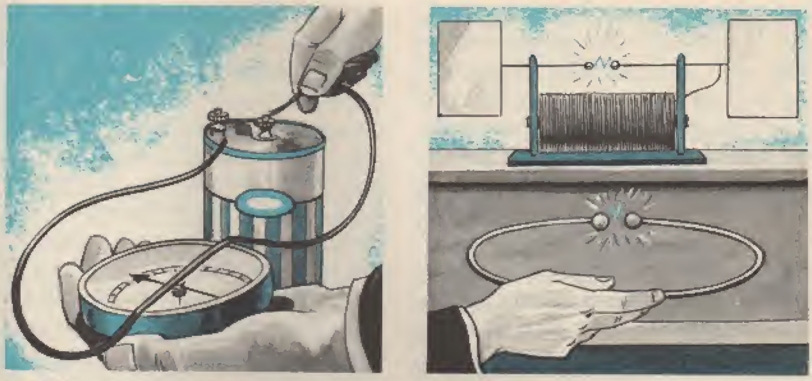
Above: The frequency is 1 wavelength per second.
Below: The frequency is 2 wavelengths per second.







The line you draw halfway between the highest and lowest parts of the waves will enable you to measure waves.



In 1819 Hans Christian Oersted discovered that an electric current flowing through a wire produces magnetism and moves the needle of a compass (left). In 1887 Heinrich Hertz showed that waves sent out by an electric spark produced another spark in a nearby metal ring (above right).

per second. All electromagnetic waves travel at a speed of approximately 186,000 miles per second.

Who was the first to detect electromagnetic waves?

In 1820, a Danish schoolteacher named Hans Christian Oersted found that, when he placed a magnetic compass near a wire carrying an electric current, the compass needle swung around to point crosswise to the wire. Oersted knew that a compass needle is a thin magnet and, therefore, some kind of magnetism would be needed to move the needle. He then reasoned that the electric current moving through the wire caused some kind of magnetism to surround the wire. Because this kind of magnetism was produced by electricity, Oersted called it *electromagnetism*. The electromagnetism surrounding any electrically charged object is called an *electromagnetic field.*

Thirty-six years later, in 1856, a young English physicist named James Clerk Maxwell studied electromagnetism. He advanced the theory that, whenever there is movement in the electric charges that cause an electromagnetic field, electromagnetic waves are broadcast by the field. Maxwell gave his theory to his fellow scientists in the form of mathematical equations.

It was not until 1888 that anyone was able to prove the existence of Maxwell's electromagnetic waves. The scientist who experimentally proved the existence of electromagnetic waves was a young German named Heinrich Hertz. He reasoned that, if a moving electric charge could broadcast electromagnetic waves, a device similar to that which produced the waves should be able to receive them and change them back to electric charges.

Hertz constructed an apparatus that could make a strong electric spark jump between the knobs on the ends of two metal rods. The knobs were less than half an inch apart. The space between them was a *spark gap*. Hertz also made a metal ring with a spark gap in it. He placed the ring several feet away from the spark-making apparatus. The two spark gaps faced each other.

Hertz made a spark jump across the spark gap between the rods. Immediately, a spark jumped across the ring's spark gap. No wires or anything else connected the two spark gaps. So, electromagnetic waves produced by the spark jumping across the spark gap between the two metal rods must have travelled to the ring. Here, the waves produced electric charges that caused a spark to jump across the ring's spark gap.

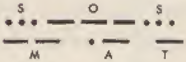
Because of his discovery of electromagnetic waves, Hertz, too, is considered a great-grandfather of radio broadcasting.

What is wireless broadcasting?

After Hertz's experiment, many scientists tried to build devices which would enable them to broadcast electromagnetic waves farther than Hertz had. One of them was Guglielmo Marconi, a young electrical engineer of Italian-Irish descent. After many experiments, Marconi attached one end of a long wire to one of the metal rods on one side of a spark gap. He raised the other end of the wire on a pole 40 feet tall. He also connected one end of another wire to the spark gap's other rod. He attached the free end of this wire to a metal plate buried in the ground. With this apparatus, Marconi could broadcast electromagnetic waves hundreds of miles. In 1901, Marconi, in Newfoundland, was able to receive the letter "s" broadcast in Morse code across the Atlantic Ocean from England.

Marconi's broadcasting and receiving apparatus was named "the wireless" to distinguish it from the telegraph and the telephone, which were used for sending messages long distances through wires. Soon, ships were equipped with apparatus to broadcast and receive wireless waves.

A short time later, wireless experimenters were broadcasting with a device that made 1,000 sparks in the spark gap each second. The sparks made



Marconi operating his early wireless broadcasting set.

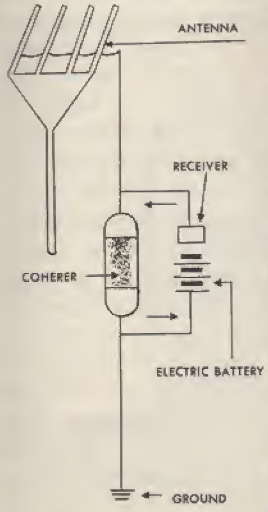
a high-pitched whine. Messages were sent by interrupting the series of sparks, making their whine last for a longer or shorter time. The result was a series of "beeps." A long "beep" was called a *dash,* a short "beep," a *dot.* Letters were made of combinations of dots and dashes. The combinations were made according to a code called the International Morse Code, which was much like the Morse Code that telegraph operators had been using to send dots and dashes over their telegraph wires.

With the Marconi wireless aboard, ships were able for the first time to call long distances for help when they were in trouble. Before wireless, ships in distress could only raise flags and fire rockets as signals that they needed help. The flags and rockets could be seen only by ships that were not over the horizon from the distressed ship; but wireless signals could be received by ships hundreds of miles away. The first time the wireless was used in sea rescue was when the *S.S. Republic* collided with the *S.S. Florida* in 1909. When the huge ocean liner *Titanic* collided with an iceberg in 1912, it sent its SOS by Marconi wireless.

Some ships still use the Marconi wireless. If you tune your radio to a spot on the dial between stations — usually in the lower numbers — you may be able to pick up the "beeps" that are the dots and dashes of wireless broadcasts from ships.

What was the world's first radio programme?

In 1904, 21 years after Edison made the first electron tube, an English electrical engineer, Professor John Ambrose Fleming, got the idea that



Marconi's receiver was a great improvement over Hertz's split metal ring. The improvements were many, but especially one which the Frenchman Edouard Branly had made. For the Hertz's spark gap, he substituted a coherer. This device consisted of powdered metal filings contained in a small glass tube. The coherer caused received electromagnetic waves to turn on and off a small electric current which could operate a signaling device, such as a telegraph sounder, thus making dots and dashes. At left, is a diagram of Marconi's early receiver, showing one part of the raised antenna.

December 1901, the day that can be considered the birthday of radio, Marconi, in Newfoundland, was able to receive a signal, which had been broadcast across the ocean from England.

Edison's invention might be used in a receiver for wireless waves. Fleming improved on Edison's electron tube by making the plate a hollow metal cylinder that encircled the filament. With a

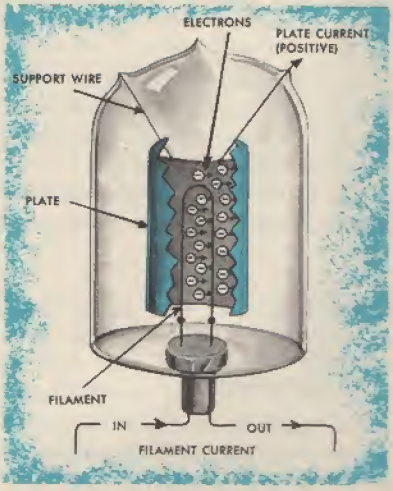


Diagram of Fleming's electron tube.

plate of this shape, electrons could be attracted to the plate, no matter in what direction they flew off the filament. This increased the stream of electrons that flowed through the wire leading away from the plate.

Meanwhile, an American electrical engineer, Professor Reginald Aubrey Fessenden, was trying to broadcast the human voice and music. He first tried to do this by using a Marconi wireless broadcasting apparatus that produced 20,000 sparks a second. This did not work, because even 20,000 sparks a second did not produce a frequency high enough.

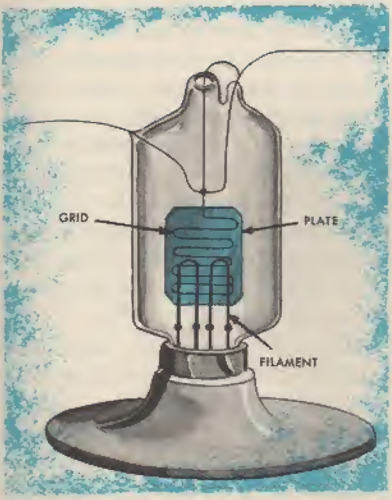
Then, Fessenden reasoned that an electric current changing its direction in a wire would produce electromagnetic waves that could be used for broadcasting. Electric current that continuously changes its direction in a wire is *alternating current* (a.c.). Most homes use alternating current for lighting and running electrical appliances. This current changes direction 120 times a second. It flows 60 times a second from the positive pole of the generator and 60 times a second from the negative pole.

Professor Fessenden used a generator whose current changed direction 200,000 times a second. Thus, he broadcast 100,000 waves a second. He attached the microphone from a telephone to the generator circuit. The microphone is the part of a telephone that you speak into. Sound waves of a voice cause the microphone to generate a weak electric current. Fessenden thought that the voice current would produce changes in the broadcast waves. When the changed waves were received by a wireless receiver, the sound of the voice would be heard. He hoped that music and other sounds, too, might be broadcast this way. On Christmas Eve, 1906, wireless operators on ships in the Atlantic Ocean were startled to hear strange sounds coming from their wireless receivers. First, they heard Professor Fessenden tell that he was beginning a broadcast. Then, they heard a gramophone recording of Handel's "Largo." This was followed by Fessenden playing a violin solo of part of Gounod's "O, Holy Night" and singing one verse. Then, he read a passage from the Bible. Finally, he wished his hearers "Merry

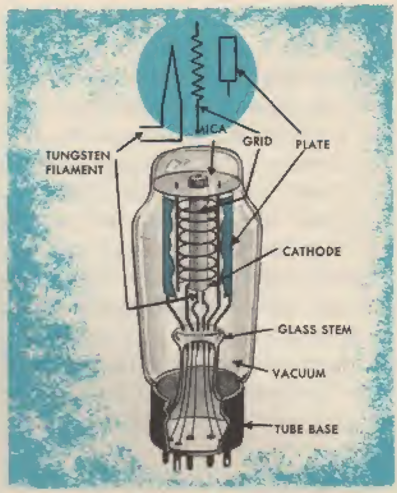
Christmas." The wireless operators, who had never heard anything but dots and dashes coming from their receivers, were flabbergasted. To make sure they were not dreaming, they asked other members of the crew to listen. They were hearing the world's first radio programme, which was coming from Professor Fessenden's radio station at Brant Rock on the Massachusetts coast, near Boston. The broadcast was heard as far south as the Virginia coast. A year later, Fessenden was able to broadcast voice and music all the way across the Atlantic Ocean to Ireland.

What was De Forest's magic lamp?

An American electrical engineer named Lee De Forest added a new part to Fleming's type of electron tube. De Forest, in 1907, made an electron tube in which he placed between the emitter and the plate a zigzag of thin wire called a *grid.*



De Forest's hand-made triode.



Modern radio tube (triode) showing the components.

Electrical engineers call De Forest's tube a *triode. Tri* means "three," and refers to the tube's three working parts: emitter, plate, and grid. *Ode* comes from the Greek word meaning "path" or "way." So, a triode is a three-way electron tube.

A modern triode has a fourth working part, a narrow tube that surrounds the emitter wire. This tube, not much wider than a pencil lead, is made of a material that gives off large numbers of electrons when heated. The hot emitter wire heats the surrounding metal tube, and the tube emits electrons. The narrow tube is called a *cathode.* Like the cathode of a wet or dry cell, the electron tube's cathode produces negative electric charges, electrons. The time it takes for the cathode to heat up is the time it takes for a radio set to "warm up."

The grid in De Forest's electron tube

enabled engineers to control the amount of electron emission easily. Also, the grid provided a way to increase, or amplify, the current entering a circuit that had a triode. Still more, a triode, connected one way, could change alternating current to direct current. Connected a different way, a triode could change direct current to alternating current. Thus, the grid changed the electron tube into a powerful and sensitive electronic device that made possible modern radio, television, radar, and hundreds of other electronic devices. De Forest's electron tube was seemingly a magic lamp.

How does a triode work?

The triode's grid can be charged electrically either negative or positive. When it is charged negative, it repels electrons from the emitter and prevents them from streaming to the plate. When it is charged positive, it has the same charge as the plate and pulls great numbers of electrons from the emitter to the plate. The charge on the grid can be varied by any amount from fully positive to fully negative. As a result, the amount of electron emission can be varied by any amount wanted, from none at all to very much.

To better understand the working of the grid, compare it to a Venetian blind. When the slats of the blind are wide open, practically no light is stopped by the blind; almost all passes through. This situation is like the grid when it has its greatest positive charge; almost all emitted electrons pass through the grid to the plate.

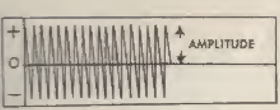
As the slats of a Venetian blind are gradually closed, less and less light passes through the blind as more and more light is stopped by the slats. As the charge on the grid gradually changes from positive to negative, fewer and fewer electrons pass through; more and more are repelled by the increasing negative charge.

When a Venetian blind is completely closed, no light passes through; when the grid is charged completely negative, no electrons pass through.

How does a radio station broadcast?

Let us begin with a performer in a radio broadcasting studio. Let us say that the performer is singing. The sound of the singer's voice moves to the microphone in a series of waves, sound waves, that are different from electromagnetic waves. All we have to know about sound waves is that they are movements of the air. When the sound waves reach the microphone, they cause certain parts within the microphone to move and change the sound into electric current. This current flows through a wire leading away from the microphone. When the sound made by the singer is loud, more current flows through the wire; when the sound is soft, less current flows. High-pitched sounds and low-pitched sounds also cause different amounts of current to flow in the wire.

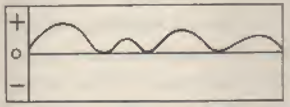
Meanwhile, in the radio station there is a series of electron tubes that are continuously sending through a wire an electric current that varies very regularly from positive to negative. This current is called a *carrier current*. If we were to draw a picture to represent car-



CARRIER CURRENT

rier current, it would look like the first illustration on page 23. You can see that each wave reaches as far above and below the horizontal line as every other wave. It is important for understanding what follows to know that the distance from the line to the peak of a wave is the wave's *amplitude*. Thus, the carrier current has very regular amplitude.

The electric current from the microphone flows to a group of electron tubes. This current is very weak, and the electron tubes amplify it. If we were to draw a picture to represent the current in the microphone wire, it would look like this illustration: You can see



AUDIO SIGNAL

that it has an irregular amplitude. The microphone current is called the *audio signal*. *Audio* refers to the sound, because sound waves generate the microphone current .

The carrier current and the audio signal go to the same circuit. Here, the irregular amplitude of the audio signal changes the very regular amplitude of the carrier current. Radio engineers say that the audio signal *modulates* the carrier current. If we were to draw a picture to represent the modulated carrier current, it would look like this illustration: As you can see, when the amplitude of the audio signal is high, the amplitude of the modulated carrier current is high. When the amplitude of the audio signal is low, the amplitude of the modulated carrier current is low.

AM WAVE

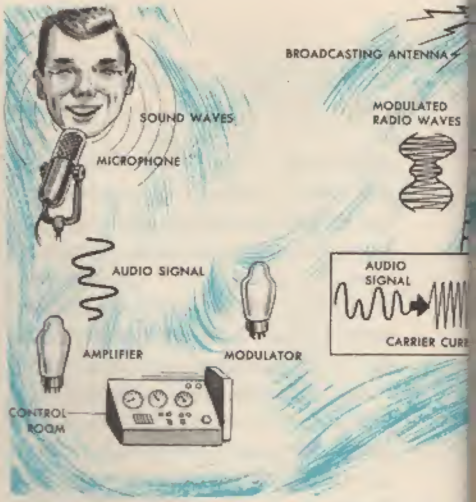
The modulated carrier current goes to another group of electron tubes that amplify it once more. Then, it goes to the arrangement of wires, usually on a tall tower, called a *broadcasting antenna*. The antenna broadcasts the modulated carrier current in the form of electromagnetic waves which we call *radio waves*. The broadcast waves are called *amplitude modulated waves*, or *AM waves*.

How does a radio receiver work?

To trap broadcast radio waves and bring them into a radio receiver, we need some way to change the electromagnetic waves back to electric current. This is done very easily, because when electromagnetic waves strike a wire or some other electrical conductor, they cause an electric current to flow in the conductor. A single wire, or an arrangement of wires, called a *receiving antenna*, is used to trap passing radio waves. Sometimes an antenna consists of several wires on one or more poles outside a house, usually on the roof. The most common antenna is a network of wires inside a radio set. Some car radios use as an antenna a flexible metal rod sticking up from the side of the auto.

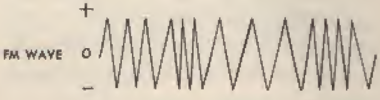
When radio waves are broadcast, they rapidly become weaker as they move away from the broadcasting station. If you live close to a broadcasting station, you know how much louder its broadcasts are than those of stations farther away. Usually, by the time radio waves reach a radio receiver, they are very weak.

The weak radio waves cause a weak current to flow in the wires of an antenna. The current may have a strength of only a few millionths of a volt. (A *volt* is the unit used to measure the strength of a moving electric charge.) This is far too little to make a loudspeaker work. When this current enters the radio receiver, it goes to electron tubes that amplify it a million or more times. The strengthened current then goes to another part of the circuit that filters out the carrier current, leaving only the audio signal. The audio signal goes to the speaker. Here, the speaker reverses the work of the microphone: it changes electric current into sound waves that leave the loudspeaker as the sound of the singer's voice in the broadcasting studio.



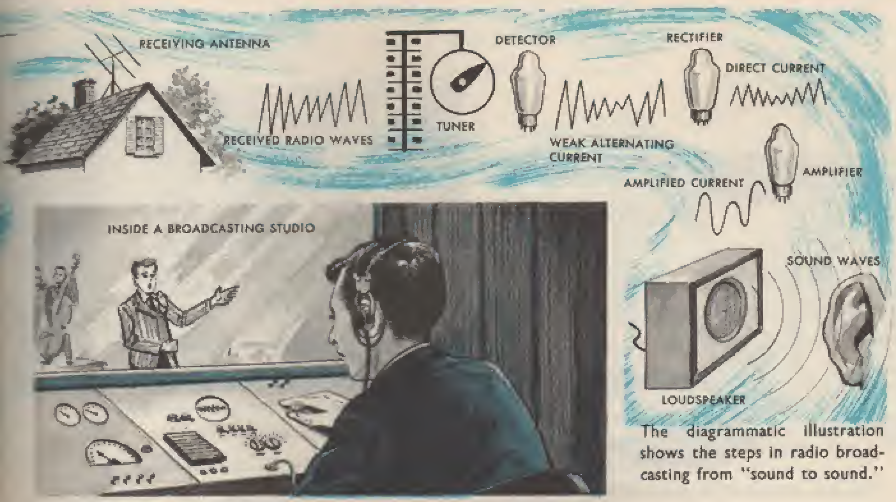
What is FM broadcasting?

You have heard of FM broadcasting. The letters "FM" stand for *frequency modulation*. You remember that "AM" stands for *amplitude modulation*. In AM, the *amplitude* of the carrier wave is modulated by the audio signal. In FM, the *frequency* of the carrier current is modulated by the audio signal. The diagram shows what happens when a carrier current has its frequency modulated by an audio signal. You remember that the electric current going to a broadcasting antenna varies from positive to negative. Whenever the current is positive, the carrier frequency is jammed together; whenever the current is negative, the carrier frequency is spread apart. The action is something like that of pushing and pulling on an accordion.



The frequencies of FM broadcasting are much higher than those of AM. FM frequencies are measured in *Megacycles* per second (or *MegaHertzes*), *Mega* meaning "million." The frequencies of AM broadcasting are measured in *Kilocycles* per second, or thousands of cycles per second.

Is there anything particularly good about FM? Yes, it is almost free of static. You know, of course, that static is the crackling and scraping sounds that occasionally come from your radio while you are listening to a programme. Static is caused by lightning and smaller sparks, such as those made by automobile spark plugs and electric motors.



The diagrammatic illustration shows the steps in radio broadcasting from "sound to sound."

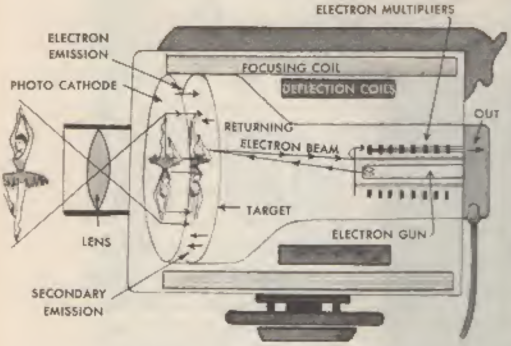
These sparks are moving electric charges; therefore, they broadcast electromagnetic waves. Your AM radio receives these waves and changes them into the unwanted sounds of static.

Static interferes with AM radio waves because it modulates the amplitude of these waves. Static does not interfere with FM radio waves because it does nothing to modulate the frequency of radio waves, and FM waves are only frequency-modulated.

How is television broadcast?

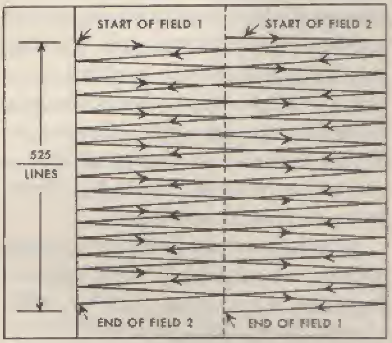
If you were to look inside a television set, you would see many things that you saw inside a radio, such as electron tubes and wired circuits. So many parts in the two kinds of receiving sets are the same, because television pictures — as electromagnetic waves of radio — are broadcast by means of electromagnetic waves that have to be detected, tuned, and amplified. In radio, the problem was to change sound waves to radio waves in the broadcasting studio, and then to change the broadcast radio waves back to sound waves in the radio receiving set. In television, the problem is to change light waves into electromagnetic waves in the television broadcasting studio, and then to change the broadcast television waves back to light waves in the television receiving set.

In a studio, when a television camera focuses on an object, light reflected from the object enters the lens of the camera. Here, the light strikes a metal screen in a large electron tube. In one type of camera, the tube is called an *image orthicon*. Inside the image orthicon, the metal screen, which is the cathode, is so thin that light passes through it as through tissue paper. The metal of which the screen is made is *photoelectric*. This means that when light strikes it, electrons are knocked out of the metal atoms. The brighter the light, the larger the number of electrons that are knocked out of the cathode. Thus, when light strikes the screen,



Schematic drawing of the image orthicon.

Schematic drawing of interlaced scanning.



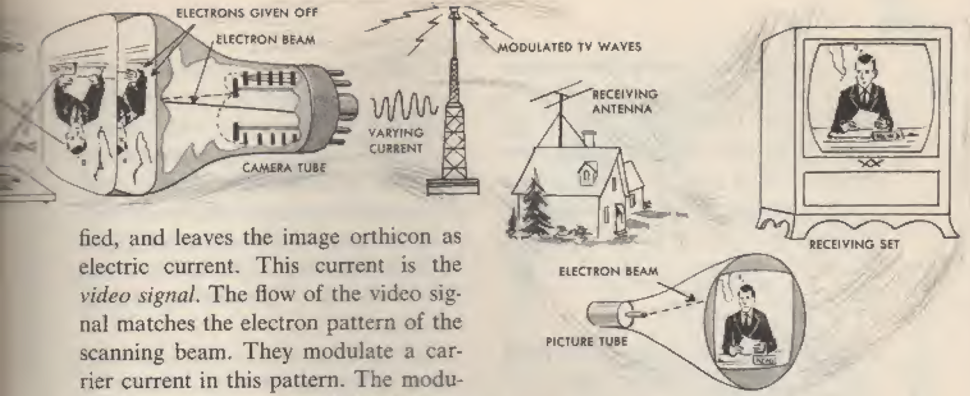
Television is much more complicated than radio. In the studio the scene is focused on the photosensitive surface of the image tube within the camera. This changes the light and shadows of the scene into varying electrical current. The current varies, or modulates, an electron beam that scans the target surface of the image section 525 times a second. The modulated beam becomes the broadcast video wave. Television antennas transmit sound and video waves separately. The sound is broadcast by FM radio. The video wave is picked up by the receiving antenna, rectified by the television receiver, and fed into the picture tube, or kinescope. There it varies the strength of a stream of electrons. As the electron stream plays across the fluorescent screen at the wide end of the tube, it produces the same picture "seen" by the camera.

electron emission takes place. The emitted electrons strike a nearby metal plate, called the *target*. Electrons are knocked out of the target in just the same pattern as those knocked out of the cathode by light entering the TV camera.

At the other end of the tube is an electron gun that shoots a beam of electrons at the back of the target. Where the target has lost electrons, it regains them from the electron beam. Where no electrons have been knocked out of the target, the beam is repelled back to the other end of the tube. As a result, the repelled electron beam has lost electrons in just the same pattern as the cathode lost them.

The electron beam sweeps over, or *scans*, the target in two successive downsweeps. In each downsweep, as the beam moves downward, it also moves from side to side in horizontal lines across the entire target. The first downsweep covers 262½ lines, and the second covers 262½ alternate lines. Each downsweep takes one-sixtieth of a second, so that the entire target is scanned in one-thirtieth of a second.

The repelled scanning beam is ampli-



Simple diagram of television broadcasting and receiving from studio to home.

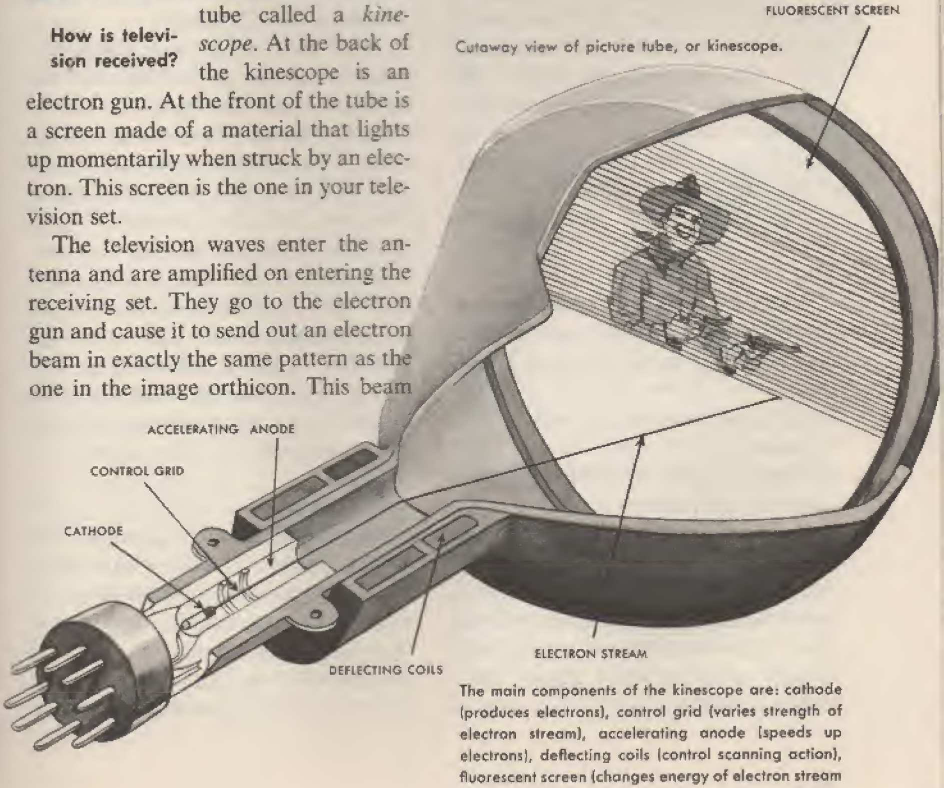
fied, and leaves the image orthicon as electric current. This current is the *video signal*. The flow of the video signal matches the electron pattern of the scanning beam. They modulate a carrier current in this pattern. The modulated carrier current is broadcast as television waves.

How is television received?

The television receiver has an electron tube called a *kinescope*. At the back of the kinescope is an electron gun. At the front of the tube is a screen made of a material that lights up momentarily when struck by an electron. This screen is the one in your television set.

The television waves enter the antenna and are amplified on entering the receiving set. They go to the electron gun and cause it to send out an electron beam in exactly the same pattern as the one in the image orthicon. This beam

Cutaway view of picture tube, or kinescope.



The main components of the kinescope are: cathode (produces electrons), control grid (varies strength of electron stream), accelerating anode (speeds up electrons), deflecting coils (control scanning action), fluorescent screen (changes energy of electron stream into light).

scans the screen at exactly the same rate — 30 times a second — as the one in the television camera. As a result, the screen lights up with exactly the same pattern of light and dark areas as that which entered the studio television camera. And you see on your TV screen just what the camera "saw" in the studio.

How does colour television work?

A colour television camera uses three image tubes; one sensitive to red light, one to green, and one to blue. The video signals from these camera tubes go to electronic equipment in which the three colour signals are combined and modulated. Then, they are broadcast as the *I*, *Q*, and *Y* signals. The I and Q signals carry the colour information — that is, the colours the cameras recorded. The Y signal carries the brightness information — how bright the things the cameras recorded were. (See illustrations on page 33.)

When the I, Q, and Y signals enter the colour-TV receiver, certain devices sort out the I and Q signals to reproduce on the screen the colours of the things in the broadcasting studio. Other devices mix the Y signal with the I and Q signals and give the colours the same brightness they had in the studio.

If the I, Q, and Y signals are picked up by the antenna of a TV receiver that is not equipped for colour, only the Y signal is used. The result is a perfectly good black-and-white picture, just as if the set were receiving a regular non-colour signal.

What is a transistor?

In 1948, three American scientists who worked for the Bell Telephone Laboratories invented an electronic device that challenged the electron tube as a means of controlling the flow of electric current. The scientists were William Shockley, John Bardeen, and Walter Brattain. The device was the *transistor*.

A transistor is a small electronic device that does the same tasks as an electron tube. A transistor can amplify and control electric current. For most uses, a transistor performs these tasks as well as an electron tube. For some uses, the transistor is better.

Transistors are very small when compared to electron tubes. Most electron tubes are about the size of two marshmallows stacked one on top of the other. Large electron tubes may be two feet tall. Even the smallest electron tubes are the size of peanuts. A large transistor is the size of a pencil eraser. Some, such as those used in earth satellites where small size and lack of weight are important, are no bigger than the period at the end of this sentence. Still other very small transistors are no thicker than a piece of sewing thread and are only about as long as this letter "i".

The small size of transistors has made possible electronic devices that could not have been made with electron tubes. For example, a pocket-size transistor radio can contain nine transistors; a radio with nine of even the smallest electron tubes would be the size of a book. The smallest hearing aid using electron tubes has a small box that the user keeps in his pocket and a wire that runs from the box to the user's ear. Hearing aids made with transistors are so small that the whole device can be placed within the earpiece of a pair of eyeglasses. The whole electronic circuit of the hearing aid is one-tenth as big as a matchhead.

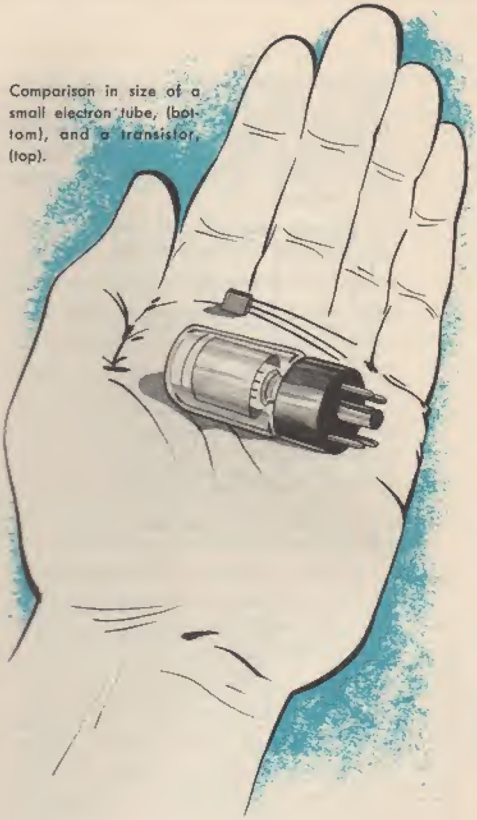
What are transistors made of?

All transistors are made of materials called *semiconductors*. We learned that conductors are materials through which electric current can flow. We also learned that insulators are materials through which electric current cannot flow. Between these two kinds of material are those through which electric current moves only fairly well. These materials are semiconductors. *Semi* means "partly," so a semiconductor is partly a conductor.

We learned that an electric current is the movement of electrons through a conductor, such as a copper wire. So, when we say that a semiconductor conducts electric current fairly well, we mean that electrons move through the semiconductor fairly well.

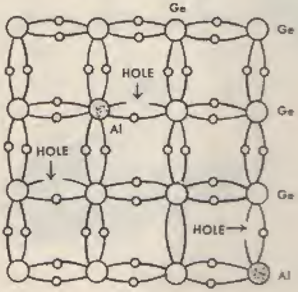
Two substances from which semiconductors can be made are the chemical elements germanium and silicon. When either of these two elements is pure, electric current moves through it very poorly. However, when, a small amount of arsenic is added to the pure germanium, the mixture becomes a semiconductor. A small amount of aluminum added to the pure silicon gives the same result. The added small amounts of elements are called *impurities*.

Comparison in size of a small electron tube, (bottom), and a transistor, (top).



What is "doping"?

Adding an impurity to a pure element is called *doping*. Doping may do one of two things. It may give the element a large number of electrons that are not bound to atoms and, therefore, are free to move. Doping with arsenic does this. Or, doping may cause the element to have too few electrons, leaving empty spaces where electrons should be. These places, empty of electrons, are called *holes*. Doping with aluminum produces holes. We can think of a hole as being a positive charge of electricity. An electron, of course, is a negative charge. Both electrons and holes move through a semiconductor. Their movement makes up an electric current.



Lattice of germanium (Ge) crystal doped with aluminum (Al).

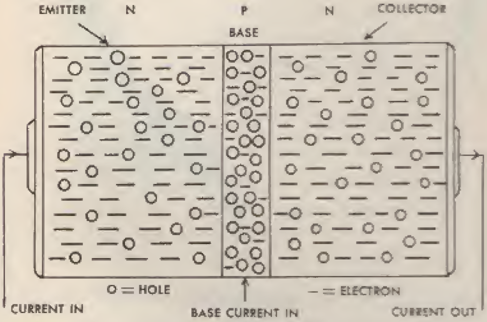
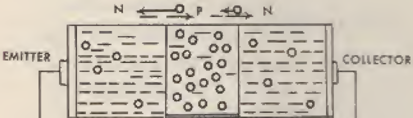


Diagram of an n-p-n transistor.



Circuit diagram of an n-p-n transistor.

In order to understand how both electrons and holes move through a semiconductor, picture a theatre in which about one-third of the seats are empty. No two empty seats are next to each other. The seats in which people are sitting represent electrons. The empty seats represent holes. Now, suppose that all the people sitting in the first row leave the theatre. Then, everyone moves forward one row, and new people take seats in the last row. If people continuously leave the first row and everyone else continues to move forward, it will look as if both the people and the empty seats are moving forward. In the same manner, when electrons move through a semiconductor, they fill holes but leave new holes in the places from which they have moved.

A semiconductor having more moving electrons than holes is called an *n-type* semiconductor. The *n* stands for "negative" and refers to the kind of electrical charge carried by electrons. A semiconductor having more holes than electrons is called a *p-type* semiconductor. The *p* stands for "positive" and refers to the kind of electric charge carried by the holes.

How is a transistor made?

There are several kinds of transistors. The kind that will best show how a transistor works is the *junction transistor*. This transistor is made out of a thin slice of one type of semiconductor material sandwiched between two thicker slices of the other type of semiconductor material. For example, in the n-p-n type of transistor, two slices of n-type semiconductor having extra electrons sandwich between them a thinner slice of p-type semiconductor that has extra holes. One of the "n" slices — the one on the side where electric current enters a transistor — is called the *emitter*. The other "n" slice — on the side where electric current leaves a transistor — is called the *collector*. Wires are soldered to the end surfaces of both the emitter and collector. The middle slice — the "p" — is called the *base*, and a wire is soldered to it, too. Where slices of semiconductor meet is called a *junction*.

How does a transistor work?

Electric current from a dry cell is sent into the emitter. This begins to move electrons and holes through the emitter, but they are blocked by the n-p junction from flowing across the base to the collector. However, when a small amount of electric current is sent into the base, the junctions no longer block the flow of electrons and holes between the emitter and collector. Then current flows all the way through the transistor.

More important, a small increase in the current flowing into the base results in a large increase in the current flowing through the transistor. This is how a transistor amplifies electric current. Also, by increasing and decreasing the amount of current that flows into the base, the amount of current that flows through the emitter to the collector can be delicately controlled.

Why are transistors replacing electron tubes?

You can easily see the likeness between a transistor and a triode electron tube. The transistor's emitter slice of semiconductor material acts like the electron tube's hot-wire filament (or cathode) emitter. The transistor's base acts like the electron tube's grid. And the transistor's collector acts like the electron tube's plate. Also, the movement of electrons in a transistor is much like electron emission in an electron tube. So, you can see why transistors can take the place of electron tubes in many kinds of electronic devices.

Transistors have certain advantages when compared to electron tubes.

Transistors use much less current. They can operate on current from dry cells the size of a small gumdrop.

An electron tube cannot work until its emitter and cathode heat up. For this reason, devices such as radios using electron tubes must have a warm-up period of several seconds. A transistor, lacking a hot emitter, begins to work as soon as the current is switched on.

The filaments of electron tubes eventually burn out. Transistors, having no filaments, last longer than electron tubes.

Large numbers of electron tubes grouped together, as in big computers, give off much heat made by their red-hot filaments. Therefore, the computers need elaborate cooling equipment. Transistors work cool. Large numbers of them may be built into a computer and never heat it up.

Transistors are very rugged. A transistor can be sealed in plastic or metal and knocked around without being broken. An electron tube, with its delicate filament and grid wires and its glass casing, is easily broken.

Transistors have some disadvantages, too. They cannot control a large flow of electric current nor amplify radio waves as well as electron tubes can.

What is a semiconductor diode?

You may have seen printed on the case of a small radio something like "7 transistors, 5 diodes." A diode is like a transistor, but is made of only two slices of semiconductor material, one a "p" slice and the other an "n" slice.

A semiconductor diode is an electronic one-way gate for electric current. It is easy to pump electrons across the n-p junction of the diode from the "n" half to the "p" half, but not in the opposite direction. This one-way electron traffic makes a diode a good *rectifier,* a device for changing alternating current to direct current by blocking half of each a.c. wave and letting the other half pass. Rectifiers in radio and television receivers change alternating house current to the direct current needed by circuits in the receivers. In industry, large silicon diode rectifiers convert great amounts of alternating current to direct current for such uses as plating one metal with another. A semiconductor diode uses much less current than an electron tube diode.

A semiconductor diode is photoelectric, generating electricity while light strikes it. Semiconductor diodes are used in artificial satellites as *solar cells,* devices that generate electric current while in sunlight.

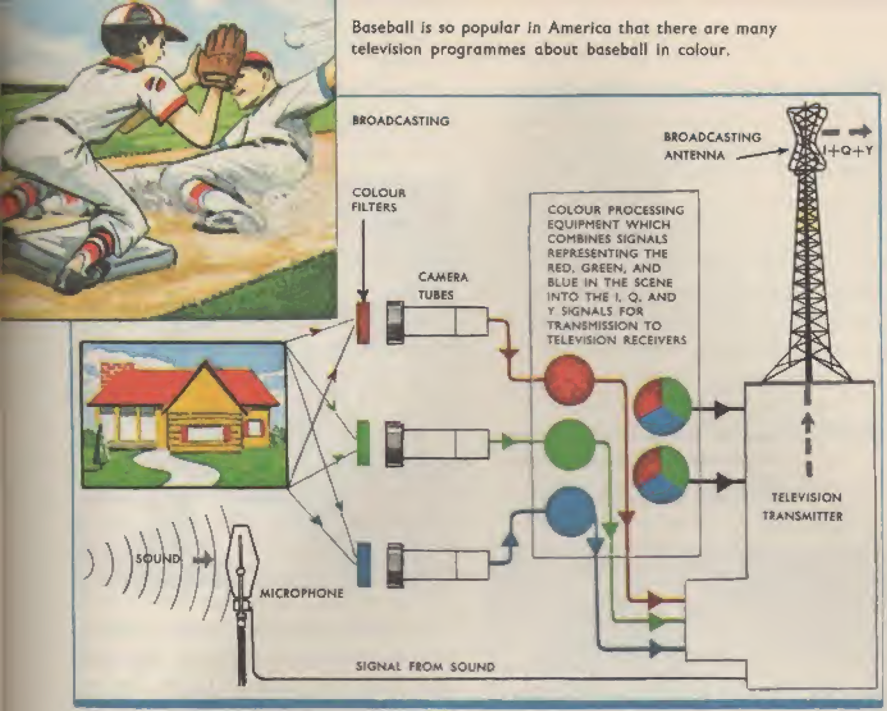
The Wonderful World of Electronic Devices

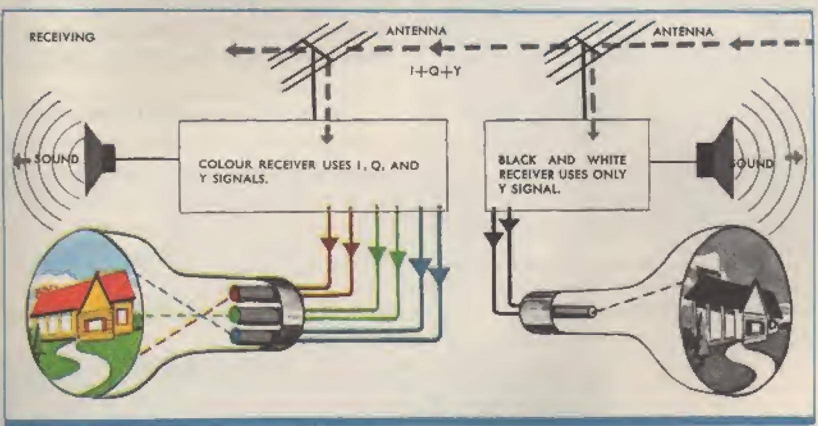
Now that we know how electron tubes and transistors work in radio and television, let us see some of the other wonderful applications of these electronic devices.

How does radar work?

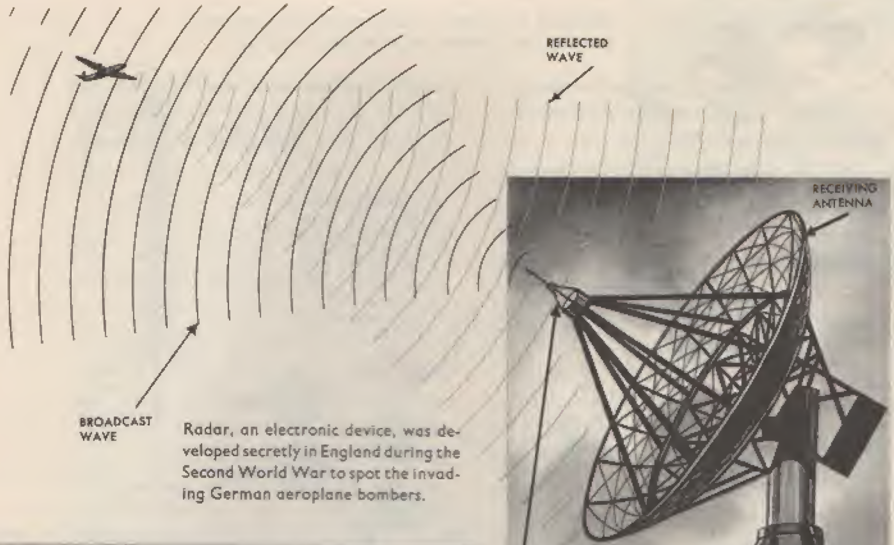
In the early days of World War II, the most famous of air battles, the Battle of Britain, was fought. The Nazis' large bomber force attacked Great Britain, intent upon destroying so much of that island that the Nazi land armies could invade it easily. Instead of succeeding in this plan, the attacking bomber force was destroyed by a much smaller number of fighter planes of the British Royal Air Force. Why was the smaller air force able to defeat the larger? There were two reasons. First, the British fighter pilots and planes were extremely good. Second, the British pilots seemed to have a way of knowing exactly where the Nazi bombers were entering the air space over Great Britain. Knowing this, the

Baseball is so popular in America that there are many television programmes about baseball in colour.

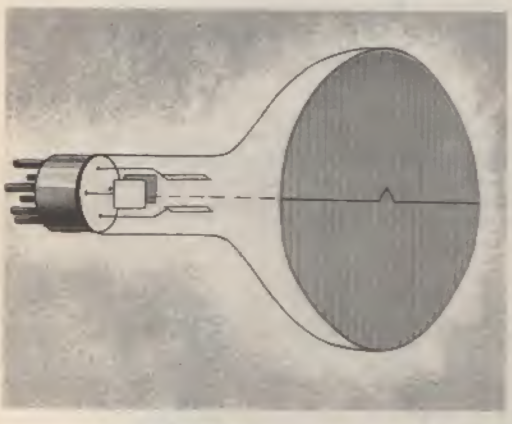




Light reflected from the illuminated scene in the television colour broadcasting studio passes through primary-colour filters on its way to the camera tube. Thus the signal from the top camera tube depends upon the red in the scene; that from the middle camera tube upon the green, while that from the lower camera tube depends upon the blue. The I and Q signals (chrominance) depend upon the different colours in the scene, while the Y (luminance) signal depends upon the brightness of the colours. Thus, while the Y signal alone will form a picture in a black-and-white TV set, all of the signals are needed to receive a colour picture.



Radar, an electronic device, was developed secretly in England during the Second World War to spot the invading German aeroplane bombers.

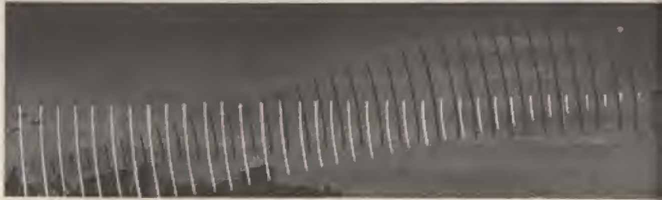


Schematic illustration of a radarscope shows the pip, the received signal that the broadcast radar wave has bounced from a solid object.

British did not have to waste most of their small number of fighter planes in patrolling the coast of Great Britain to look for approaching bombers. Instead, the fighter planes could be concentrated where the enemy bombers were arriving.

The British were able to spot the invading bombers by means of a new and secret electronic device called *radar*. (The word *radar* is made up of the italicized parts of the words, *ra*dio, *d*etection, *a*nd *r*anging.) Radar is a kind of radio broadcasting.

A radar transmitter broadcasts very



Night scene over London during Nazi bombing in 1940. Radar waves bounce from invading Nazi bombers and pinpoint their position.

short radio waves. These waves are reflected from solid objects in much the same way that light is reflected from the objects it strikes. The shorter the radio wave, the better it is reflected. Radar waves are among the shortest that can be broadcast. They are called *microwaves*.

A radar antenna is shaped like a huge cereal bowl. Microwaves are broadcast from a rod sticking out from the centre of the inner side of the bowl. If the waves strike an object, they are reflected back to the antenna. All the returning waves are reflected from the inside of the bowl to the tip of the rod.

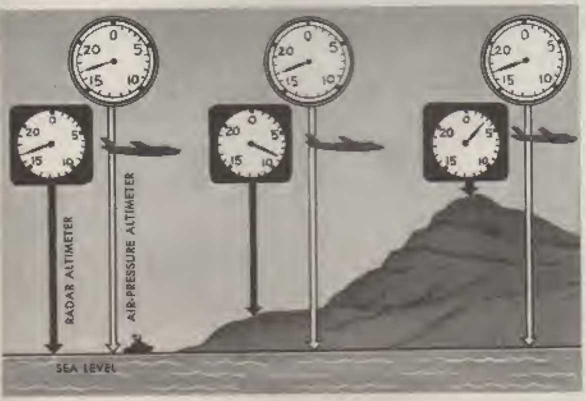
Radar waves, like all electromagnetic waves, travel at a speed of approximately 186,000 miles a second. If they strike an aeroplane 10 miles from the antenna, the reflected radar waves are back at the antenna in less than a nine-thousandth of a second. In order that the reflected waves do not interfere with the broadcast waves, radar is broadcast in very short bursts. Each burst is called a *pulse*. The time between pulses is the time in which the reflected waves are picked up by the antenna.

The reflected waves generate an electric current in the antenna. The current goes through a circuit to a special screen — much like a television screen — on which the object reflecting the waves shows up as a small spot of light, which is called a *blip*. During the Battle of Britain, radar operators saw the approaching Nazi bombers as blips on radar screens and radioed the Royal Air Force fighters where to meet the attacking planes.

Radar has many peacetime uses, too. Clouds reflect radar waves. This enables commercial airline pilots to detect storms in their paths and to fly their airliners around them.

Pilots in aeroplanes without radar are able to tell how high above the earth they are by means of a device called an

The radarscope in an aeroplane is used to detect storms and other disturbances in the air more than 100 miles away.



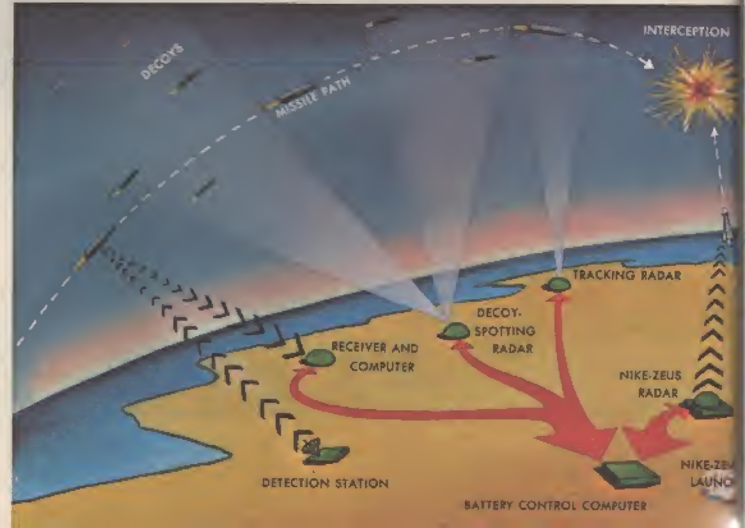
The air-pressure altimeter gives the pilot an indication at what height above sea level the plane is flying. The radar altimeter indicates how close to the earth's surface the plane is flying.

altimeter. This device depends on the fact that air pressure decreases as we go higher above the surface of the earth. By measuring air pressure, the altimeter shows at what height the aeroplane is flying. But, sometimes, especially in mountainous country, the altimeter does not register accurately. Here, air pressure is influenced by up-and-down currents of air. A pilot, looking at his altimeter when his plane is flying in a strong down-current of air, may think that he is flying higher than he actually is. As a result, he may fly too low and, at night or in fog, he may crash into a mountain. But radar can provide him with a foolproof altimeter. A radar signal is broadcast downward from one wing tip of the plane. The signal bounces off the ground and is received at the other wing tip. The time it takes for the radar signal to make a round trip — from wing tip to ground to wing tip — is automatically calculated to give the height of the plane above the ground. Since radar is not influenced by air currents, the pilot can tell how high above the ground he really is, no matter where he is flying.

What is sonar?

During World War II, while radar was combating enemy planes, another new electronic device, *sonar*, was combating enemy submarines.

Radar cannot be used to detect submarines under water. Radar waves are reflected from any material as dense as water. Also, radar waves cannot be broadcast through anything that will



Radar and computers are the heart of the North American Air Defense Command.

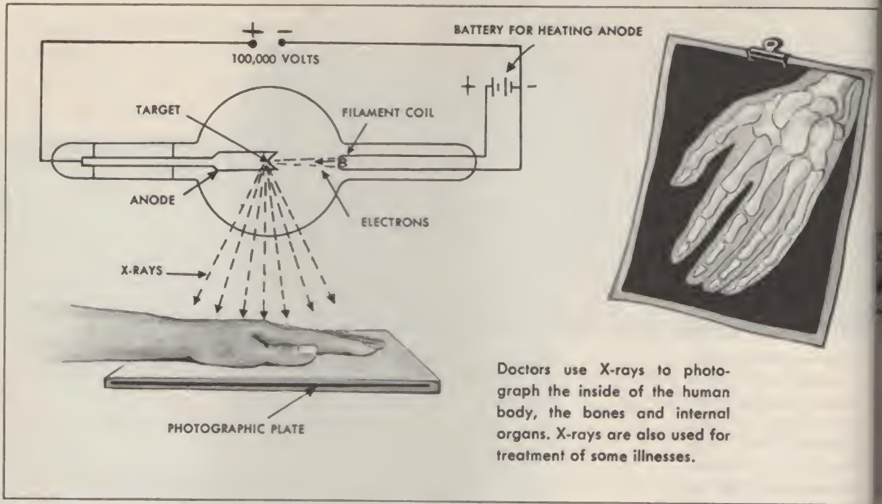
A bat has natural sonar. It sends out sound waves (curved lines) and receives an echo (dashed lines), enabling the bat to tell the distance and location of obstacles and also insects it seeks for food.

By measuring the time that a sound wave takes to travel to an obstacle and back, one can figure out the distance and location of the object. A ship, equipped with sonar, can locate a submarine by this method.

conduct electricity, and sea water is a very good conductor.

Sound waves travel very well through water. So, sonar uses electronic devices that cause an instrument in the bottom of a ship to send pulses of very strong sound waves through the water. If a submarine, or any other solid object, is within the range of these sound waves, they are reflected back to the ship. Here, a microphone picks them up and transforms them into electric current. The current goes to an electronic device that shows in what direction and how far the reflecting object is. If the reflecting object is an enemy submarine, and the ship using the sonar is a warship, the submarine may be found and destroyed.

Sonar has peacetime uses, too. It is used by fishing fleets to locate schools of fish. Also, ships can use sonar to learn how deep the water below them is. They send sonar waves to the bottom of the sea and measure the time it takes the waves to bounce back, just as airplanes learn how high they are by bouncing radar waves off the surface of the earth.



Doctors use X-rays to photograph the inside of the human body, the bones and internal organs. X-rays are also used for treatment of some illnesses.

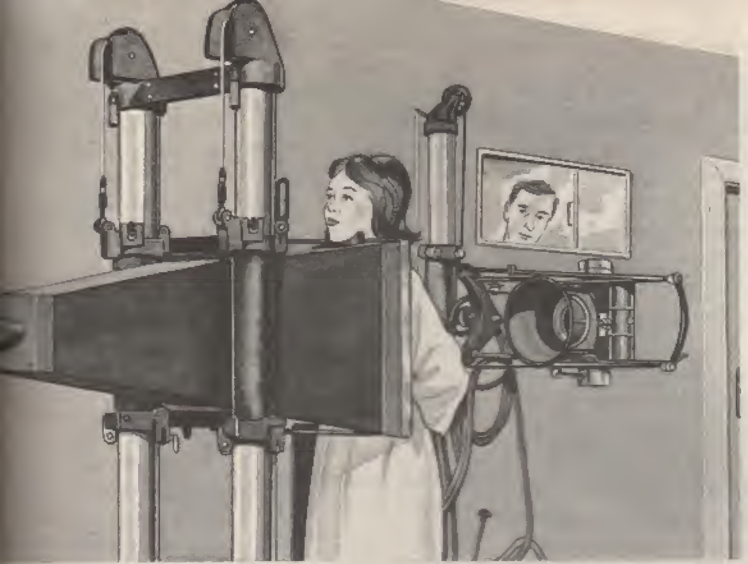
How does electronics help doctors?

We have learned that X-ray cameras were among the first electronic devices, and also that X-rays are used to photograph things inside the human body.

The main part of an X-ray camera is the X-ray tube. This is a glass tube which contains an electron gun that shoots a beam of electrons at a very hard metal target. Upon being struck by electrons, the target shoots out a beam of electromagnetic waves called *X-rays*. These waves have a wavelength even shorter than the microwaves of radar. X-rays can pass through solid materials, passing through some materials easily and through others less easily or not at all.

Doctors use X-rays to photograph the inside of the human body. X-rays easily pass through the body's thinner organs such as the skin and through softer tissues such as fat. X-rays do not easily pass through thick, more solid body parts such as big muscles or the liver. Hard body parts such as bones and teeth almost entirely block the passage of X-rays. To obtain an X-ray photograph, a sheet of photographic film is placed on the side of the body opposite the entering X-rays. When the X-rays leave the body, they strike the film. Those X-rays that easily passed through the body's thinner, softer parts darken the film the most. Those X-rays that were blocked in varying amounts by the body's more solid parts darken the film less or not at all. When the film is developed, the result is a picture of the inside of the body.

Sometimes, instead of using photographic film, a doctor may place a patient in front of a screen somewhat like a television screen, although much larger. When X-rays strike any part of this screen, it lights up. X-rays, after passing through the patient's body,



Regular periodic chest X-ray examinations are very useful for early detection of many chest diseases.

strike the screen and make a picture of what is inside the patient's body. X-ray cameras that use these large screens are called *fluoroscopes*. The fluoroscope enables the doctor to see immediately — without waiting to develop photographic film — what is inside the patient's body. Also, fluoroscopes show moving parts of a body such as a beating heart.

X-rays can be dangerous. If living body cells are exposed to X-rays for too long a time, the cells will be killed. This is why patients are exposed to X-rays for no more than a second — and usually less — for each X-ray picture the doctor takes. The danger of exposure to X-rays is the reason that doctors and others who work with X-rays wear aprons and gloves that have lead worked into the fabric. Also, the X-ray workers stand behind lead screens when the X-ray tube is turned on. Lead stops X-rays very well.

There is, however, a good side to the fact that X-rays can kill body cells. Cancer cells are more easily killed by X-rays than are healthy body cells. So, doctors treat some kinds of cancer by exposure to X-rays strong enough to kill the cancer cells, but not strong enough to kill the healthy body cells surrounding the cancer.

Using transistors, a broadcasting station can be made so tiny — the size of a grain of rice — that it can be placed inside the heart. By listening to the broadcasts of heartbeats, doctors can learn how a patient's heart is working. Another tiny broadcasting station is put into a capsule that a patient swallows. As the capsule moves through the patient's stomach and intestine, different digestive juices cause the capsule to broadcast different wave patterns. These wave patterns give doctors useful information about the patient's stomach and intestine.

What is a photocell?

One day when the German physicist, Heinrich Hertz, was experimenting with his spark gap apparatus, he found that the spark was larger when he shined an intense beam of light on the spark gap. Other scientists learned that they could increase the flow of electricity in certain metals by shining light on them. Still later, scientists learned that these same metals emitted electrons under light. Metals that do this are said to be *photoelectric*. *Photo* is the ancient Greek word for "light." So, a photoelectric metal is one that makes electricity by means of light. Among such metals are the chemical elements sodium, potassium, lithium, and cesium. We learned that a TV camera contains a screen of photoelectric metal.

The cathode of an electron tube can be made of one of the photoelectric metals. When light shines on this kind of cathode, electron emission takes place, just as it does when the cathode of an electron tube is heated.

Electron tubes made with photoelectric cathodes are called *photoelectric cells*, or *photocells*. A photocell consists of a glass bulb whose inside is coated with a photoelectric metal. A small circular window is left in the coating. The outside of the bulb is covered so that light cannot pass through any part of the glass except where the circular window is located. In the centre of the bulb, just below the window, is an anode that serves exactly the same purpose as the anode, or plate, in any electron tube; it collects electrons emitted by the cathode. To do this, the anode is kept positively charged so that it will attract the electrons emitted by the photoelectric metal cathode. A wire, embedded in the photoelectric metal, is sealed into the glass bulb to complete a circuit.

When a beam of light passes through the photocell's window, it strikes the photoelectric metal. This causes the metal to emit electrons. The electrons are attracted to the anode from which they flow out of the photocell as electric current.

How do self-opening doors work?

Perhaps, when in a public building, you have approached a door that opened just as you were about to open it, although neither you nor anyone else touched the door. A photocell was part of the machinery that opened the door. Here is how it worked. A beam of light, passing across your path a couple of feet in front of the doorway, was directed at a photocell. The light entering the photocell caused an electric current to flow. This current went to a magnet that held a switch open. When you approached the door and walked through the light beam, the light was cut off from the photocell for a moment. During this moment, no current flowed out of the photocell. As a result, the magnet no longer held the switch open. The closed switch sent electric current (from a source other than the photocell) to a motor that opened the door for you.

The photocell "saw" you when you approached the door. Because a photocell works as if it can see, it is sometimes called an "electronic eye."

Photocells are used on cameras to measure the amount of light that enters

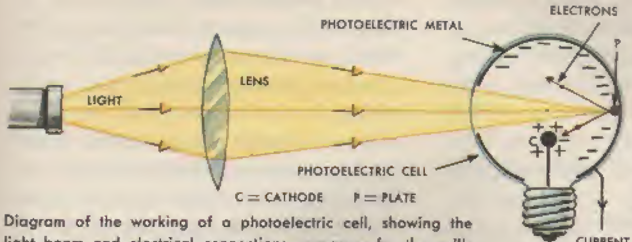
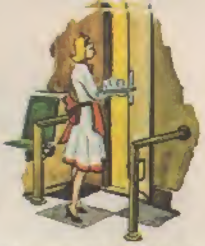
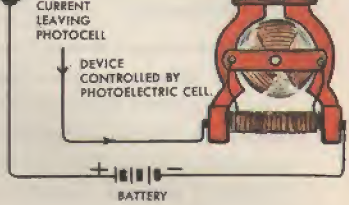
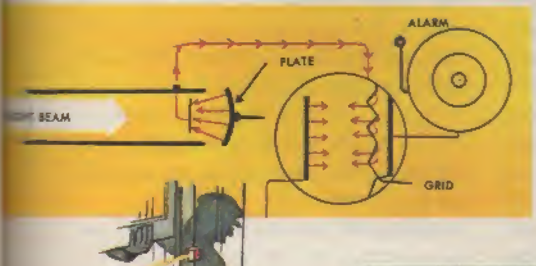


Diagram of the working of a photoelectric cell, showing the light beam and electrical connections necessary for the cell's operation.

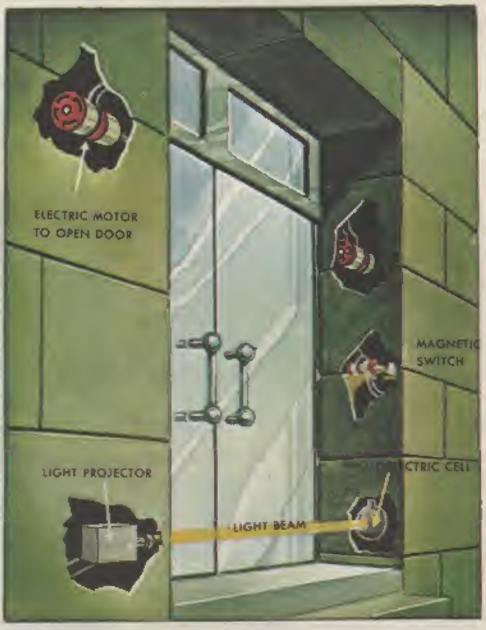


When someone nears the door, the light beam is interrupted and the door swings open.





Many a burglar alarm has trapped an intruder or at least scared him away. This is a schematic illustration of how it works: Light shines on the cathode of the photocell which emits electrons that jump to the anode and flow into the grid of an amplifier tube. This keeps the grid negative and prevents the electrons from moving to the plate. The moment the light beam is interrupted, the electrons can flow to the plate, forming an electric current that operates the alarm.



This is a diagram showing the working of a door operated by an electric eye. By replacing the electric motor with a bell, you can change it to a burglar alarm system.

a camera's lens. The electric current produced by the photocell is used to regulate the size of the lens opening, thereby giving correct exposure to the film.

How can "black light" catch burglars?

Light is made up of electromagnetic waves of very short wavelength and very high frequency when compared to radio, television, or even radar waves. Each colour of light has a frequency and a wavelength different from those of other colours. Red has the lowest frequency and the longest wavelength. Then the frequencies of orange, yellow, green, blue, and indigo become higher and the wavelengths shorter until we reach violet. Violet has the highest frequency and shortest wavelength. The electromagnetic waves that have a frequency a little lower than red and the waves with a frequency a little higher than violet are also said to be kinds of light. Waves with frequency a little lower than red are *infrared light. Infrared* means "below red." Waves with frequency a little higher than violet are *ultraviolet* light. *Ultraviolet* means "above violet." Although we call infrared and ultraviolet kinds of light, we cannot see them. So, they are sometimes called "black light."

Suppose we wish to guard something — let us say, the door of a storeroom. We can shine a beam of "black light" — perhaps ultraviolet — across the doorway so that the light enters a photocell. As long as the beam enters the photocell, electric current flows from the photocell. This current goes to an electric switch that remains open as long as the current flows through it. When the current is cut off, the switch closes and causes a burglar alarm bell to ring.

Now, suppose that a burglar opens the door to the storeroom. As he enters the door, he blocks the beam of ultraviolet light from shining into the photocell. The switch closes, and the alarm bell rings. The switch is constructed so that it will not open again when the burglar has passed through the beam and the light again enters the photocell. So, the bell continues to ring. Since "black light" is invisible, the burglar is not aware of the alarm until he sets it off.

In America one department store has trained dogs to walk up and down the aisles of the store at night. Each dog patrols a route that he has been trained to walk. At intervals along the patrol route are photocells. As the dog breaks the light beam, a small bulb lights up

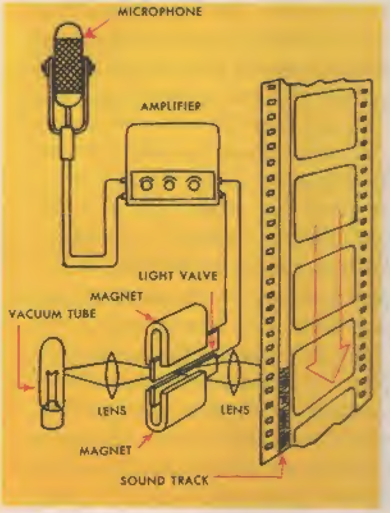
on a board in a room where a man is watching. When the dog arrives at the end of his patrol route, the last photocell turns off all the bulbs on the board. Then, as the dog begins his route again, the bulbs go on again, one by one. If a bulb does not light, the man watching the board knows that the dog did not patrol his route correctly. This might have happened because a burglar has harmed the dog or because the dog has attacked the burglar. Guards are then sent to the floor on which the dog was patrolling to learn what has gone wrong.

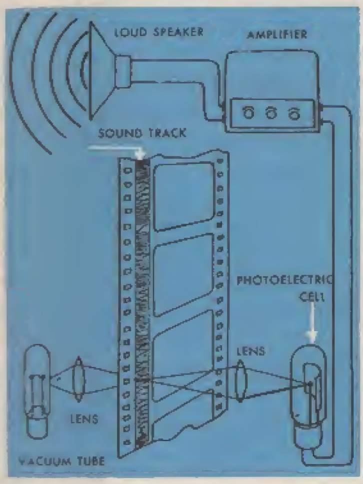
How are sound films made?

In their early days, moving pictures were silent. In order to tell the audience what an actor was saying, printed words were projected onto the screen. Years later, films used gramophone records to bring to the audience the sounds of what was being shown on the screen. The records were recorded while the film was being filmed. When the film was shown in the cinema, the records were played. Sometimes, the film and a record got out of step, and what the actors were saying did not have much connection with what they were doing. Finally, as is done nowadays, sound was recorded right on the film alongside the pictures.

While a film is being made, a microphone in the camera picks up the actors' voices and other sounds from whatever the camera is filming. The microphone changes the sound into electric current of varying strength. The current goes to two magnets that open and close a slit between two flat pieces of metal. When the current coming from the microphone is strong, the slit is widened. When the current is weak, the slit is narrowed. A beam of light is directed through the slits and falls on the film alongside the light that is entering from the lens. When the film is developed, the varying amounts of

Trained dogs walk up and down the aisles of a department store at night (left). A guard watches the board in a separate room (right) where light bulbs light up as the dogs break the invisible light beams crossing the aisles.





The diagram above illustrates the recording of sound on film to make the soundtrack.
The diagram at right shows how the sound is taken off the film when it is projected.

light from the widening and narrowing slits show up as a row of light and dark areas alongside the pictures. This row is called the *sound track*.

When the film is projected in a theatre, a special light bulb shines a beam through the sound track. This beam of light continues on to a photocell. The darker parts of the sound track block off some light so that less reaches the photocell. The lighter portions of the sound track let more light reach the photocell. The variations in light are changed by the photocell into electric current of varying strength. The electric current goes to loudspeakers that change the current into sound, just as do the speakers of a radio or a tape recorder.

Why do electrons give us the best microscopes?

We learned from the first part of this book that microscopes using electrons can magnify much better than those using light. Let us now see why this is true.

If light strikes an object and is reflected to our eyes, we see the object. If an object blocks light from reaching our eyes, we see the object only as a dark area. We say that the object casts a shadow to our eyes. However, if the object is smaller than the smallest wavelength of light, the light cannot be reflected from the object nor can the object cast its own shadow. If we substitute a beam of electrons for the light, we find that the electron beam can be

Shooting a film today is quite an enterprise, not only from the artistic angle, but from the technical point of view as well. Lighting, camera position, and placement of the microphones for background sounds and voices, all have to be calculated and tried out before the director can cry, "Lights, camera, action!"

reflected from objects too small to reflect light. These same objects can cast a shadow when in an electron beam. A beam of electrons is used in an *electron microscope*.

The electron beam starts as electron emission from a heated filament. The electrons pass between magnets that focus the beam just as glass lenses focus a beam of light. The beam then strikes the object we wish to magnify. The electrons either pass through the object or glance off it. If the electrons pass through the object, more pass through its thinner parts and less through its thicker parts. If the electrons glance off the object, they cast its shadow. After passing through the object or glancing off it, the electrons are focused twice more by magnetic lenses. When the electrons strike the object, they cause it to give off light in varying amounts. Thus, the object can be seen through a series of glass lenses by the operator of the electron microscope. This enables him to focus the microscope.

The beam of electrons enables us to magnify objects more than 30,000 times their natural size. Then, by enlarging the picture made by the electrons on the film, we can further magnify objects to as much as 250,000 times.

One of the great triumphs of the electron microscope has been to reveal *viruses,* the smallest known living things. Viruses cause many diseases, among which are measles, mumps, chicken pox, smallpox, rabies, and polio. The electron microscope may help us to conquer these diseases by enabling us to work on viruses.

What are communications satellites?

Radio AM waves can be broadcast to any place on earth, no matter how distant. They can even be broadcast completely around the earth. The reason that these waves can be sent such long distances is that they can be reflected, or bounced, from a region of air called the *ionosphere*. This region, which is between

20 and 200 miles above the earth's surface, is occupied by electrically charged particles. The particles are atoms of the gases that make up the air. These atoms have lost one or more of their electrons and, therefore, are electrically charged. Such atoms are called *ions* and from them the ionosphere gets its name.

Radio AM waves that travel diagonally upward from a broadcasting antenna strike the ionosphere and bounce down to earth, striking the ground at a point many miles from the broadcasting antenna. Then, the waves may bounce from the earth back to the ionosphere. These bounces, from earth to ionosphere and back to earth, may continue until the broadcast waves have travelled completely around the earth.

Television and radio FM waves are not reflected from the ionosphere but pass through it. Because these waves cannot bounce from ionosphere to earth, they cannot be broadcast long distances. They can be broadcast to receivers only as far from the broadcasting antenna as the horizon. Upon reaching the horizon, the broadcast waves travel off the surface of the earth and into space. When your TV receives broadcasts from places beyond the horizon, the television and radio FM waves have been brought to your local broadcasting station through wires running across country. Or, the broadcasts were carried long distances by being rebroadcast from mountaintop to mountaintop across the country.

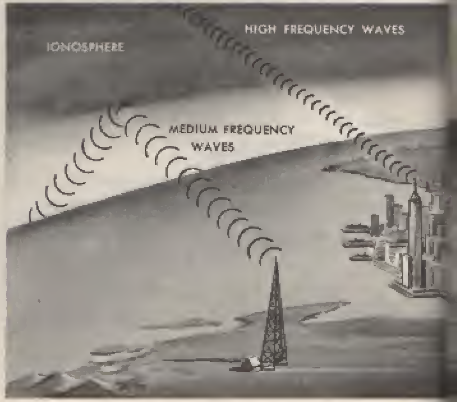
There is, however, a way to send television and FM waves to any part of the earth — by the use of *communications satellites.*

The first communications satellite was a huge aluminum-foil balloon with a diameter equal to the height of a 10-story building. This satellite was named *Echo I.* In the summer of 1960, *Echo I* was launched into orbit around the earth. The balloon circled the earth at a height of 1,000 miles. Radio and television waves broadcast to the balloon bounced back to earth. This bounce made it possible to broadcast television and FM waves about 3,000 miles.

In the summer of 1962, a second kind of communications satellite was placed into orbit around the earth. This satellite, named *Telstar I,* was a small radio and television broadcasting station. Instead of simply reflecting broadcast waves, *Telstar I* received radio and television broadcasts, recorded them, and then rebroadcast them.

Suppose a communications satellite like *Telstar I* is to broadcast a TV programme from the United States to Europe. The broadcasting station that is

While AM radio waves and all other medium-frequency waves are reflected by the ionosphere, television and FM waves and all other high-frequency waves pass through it and out into space.



to send a programme to the satellite is on the East Coast of the United States. The satellite is so far above the earth that the East Coast station can begin to broadcast as soon as the satellite starts to cross the United States from the west. The TV programme, including the sound on FM, is finished when the satellite is well over the Atlantic Ocean. In the satellite, recorders have been storing the TV programme on magnetic tape. When the satellite approaches the coast of Europe, a broadcasting station in England or France sends the satellite a command to begin broadcasting. The satellite then broadcasts the programme it has stored on tape. The European station receives the broadcast and rebroadcasts it on frequencies that can be received by TV sets in European homes.

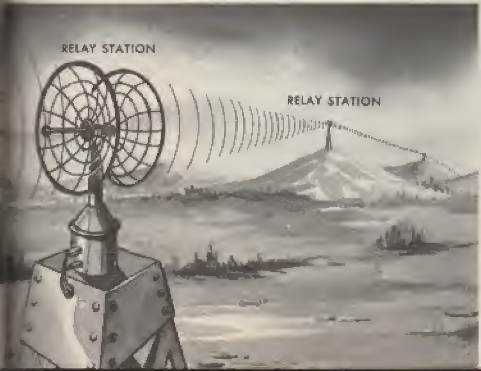
The communications satellite can receive a programme at the same time it is broadcasting another. If the European station wanting to broadcast to the United States begins to broadcast to the satellite at just about the time the satellite begins to broadcast to the European station, the satellite records the European programme. It then travels all the way around the earth until it reaches the western coast of the United States. Here, it begins to broadcast the stored European programme to a station on the United States East Coast.

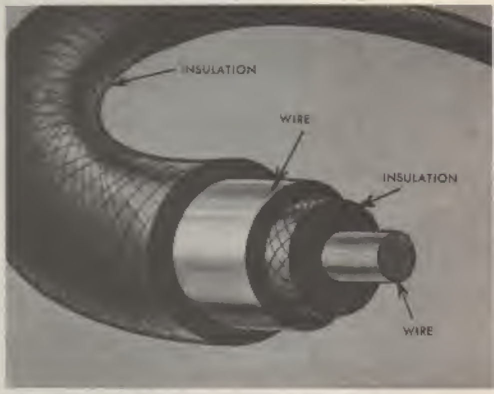
Besides rebroadcasting television and radio programmes, communications satellites receive and rebroadcast trans-Atlantic telephone calls. Also, they receive and rebroadcast photographs, maps, and other illustrations for newspapers and magazines. In addition, these satellites gather scientific information about conditions in space and send this information to earth.

Telstar I was followed by another very similar communications satellite named *Relay I*. Then, *Telstar II* was put into orbit and was followed by *Relay II*.

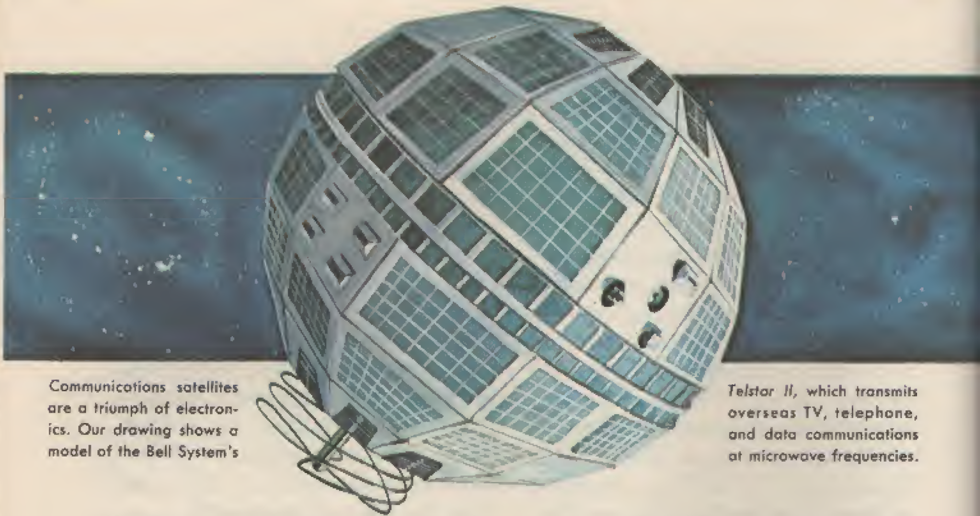
In 1963, a new type of communications satellite was launched. This was

FM waves, television waves and microwaves have to be transmitted from relay station to relay station or have to be sent by special wires.





The wire that carries TV waves is called a "coaxial cable" and has to be specially built to serve its purpose. The wire carrying the current is heavily insulated and is within a hollow wire, also heavily insulated for protection. The outside wire shields the current and prevents the rapidly vibrating current from broadcasting electromagnetic waves as if it were an antenna.



Communications satellites are a triumph of electronics. Our drawing shows a model of the Bell System's *Telstar II*, which transmits overseas TV, telephone, and data communications at microwave frequencies.

Syncom I. It was placed in an orbit 22,300 miles above the earth, and given a speed that caused it always to remain above one location on the earth's surface; as the earth turned on its axis, *Syncom I* turned in its orbit at a speed that kept it above one spot on the earth's surface. From a height of 22,300 miles, this satellite could broadcast to any place on one-third of the earth's surface. Three "stationary" communications satellites, in orbit 22,300 miles out in space and at equal distances from each other, can cover all of the earth's surface with their broadcasts. Working together, the three satellites are able to send a broadcast to any place on earth.

Electronics and You

Radio, television, radar, and the many other electronic devices that you have just read about may make it seem as though the field of electronics is very well explored. This is not so. The process of electron emission, whether in electron tubes or transistors, offers a continuing challenge to those who are clever enough to use it. As long as some process can be made to produce even the smallest amount of electric current, then electronics can amplify that current and control it in some new and useful manner.

For example, using an electronic telescope, called a *starlight scope*, soldiers in combat can see as well by starlight as by moonlight. Very sensitive electronic devices within a starlight scope can change reflected starlight into electric current, then amplify the extremely weak current and change it back to light, making a bright image of whatever the scope is pointed at.

Electronics engineers face and meet these challenges in the field of electronics. Perhaps you would like to be one of them.


HOW AND WHY

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